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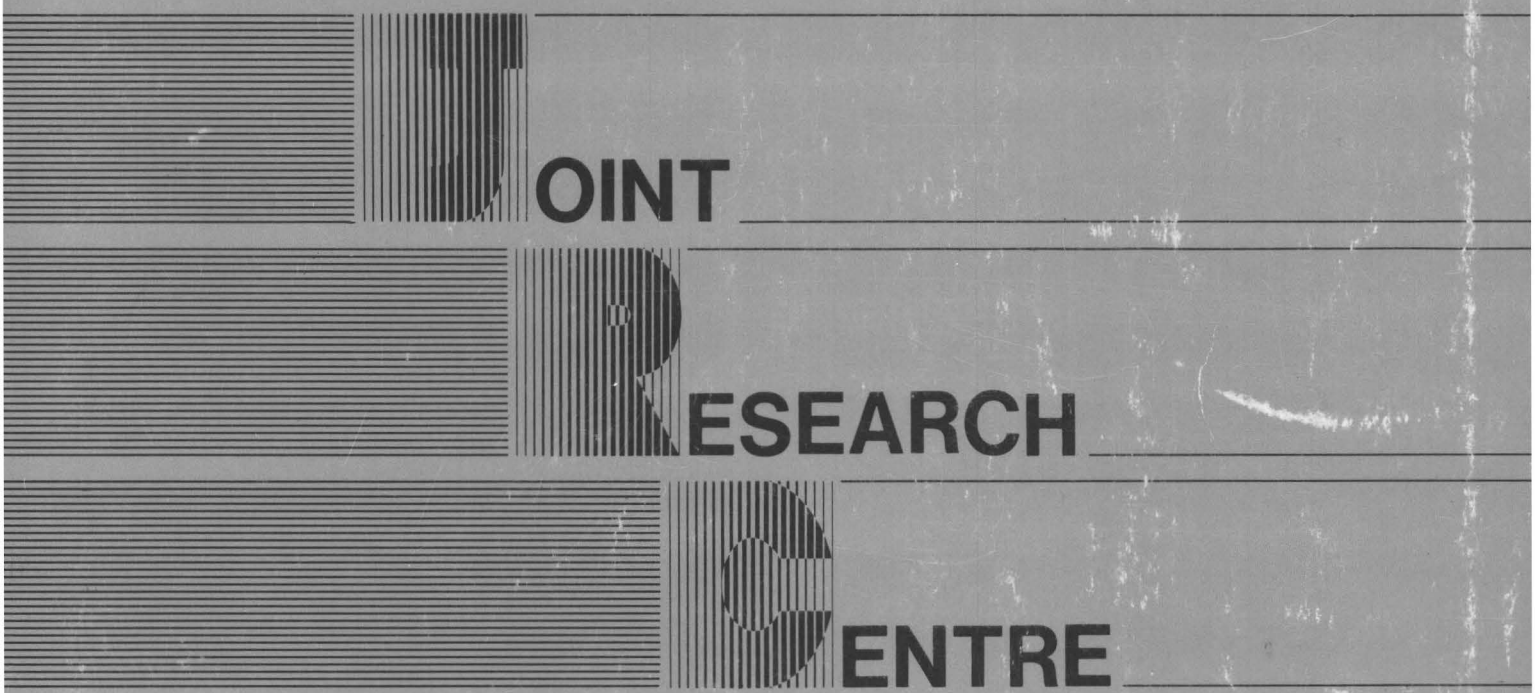

ISPRA ESTABLISHMENT-ITALY

biannual report
1974 and 1975

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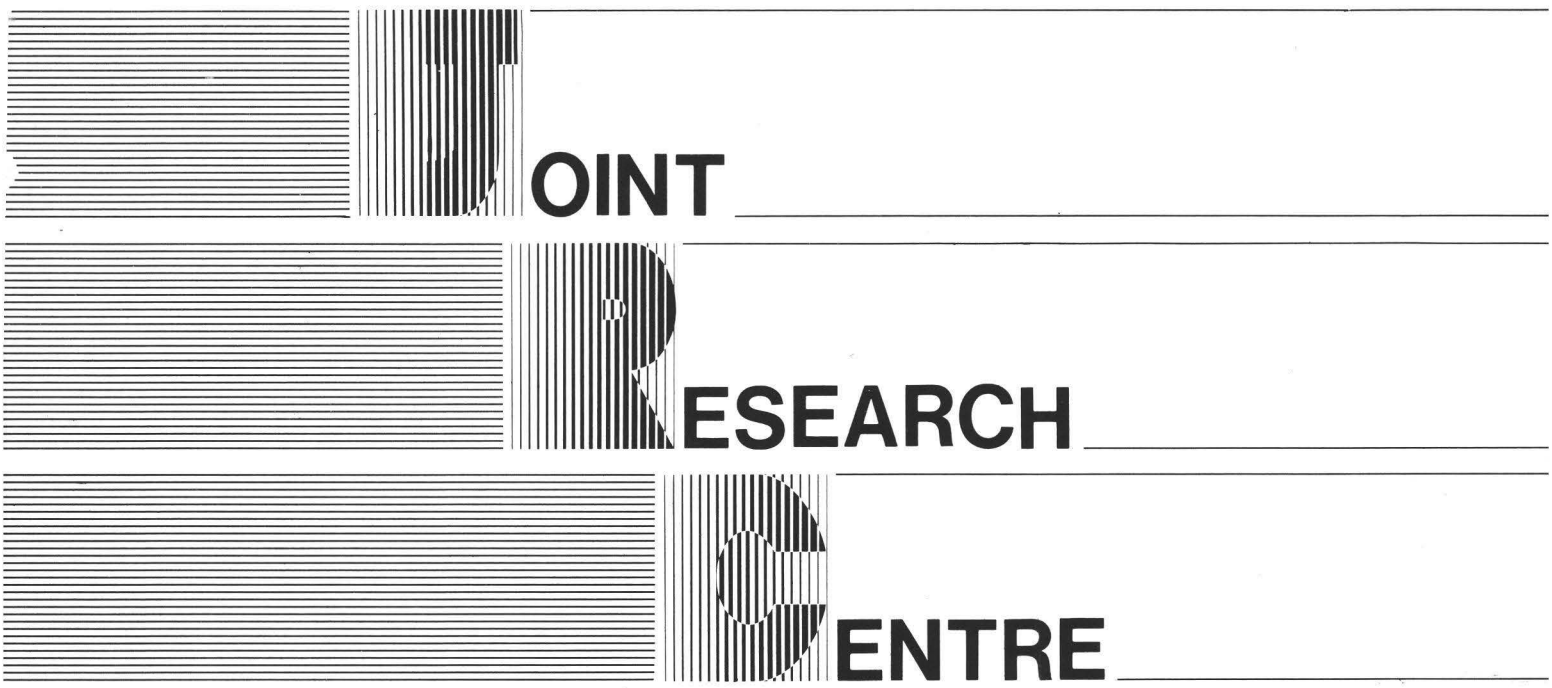

ISPRA ESTABLISHMENT-ITALY

biannual report
1974 and 1975

Abstract

This report is a comprehensive review of the work carried out during 1974 and 1975 in the Ispra establishment of the Joint Research Centre. Part one is devoted to a description of the activity carried out within the context of the running programmes. In the second part are described, from the viewpoints of the Scientific Departments of the Centre, some of the most relevant scientific and technical achievements. Part three treats both the technical and administrative support activities. A list of publications issued by the Ispra Scientific staff is given at the end.

1974 - 1975 — JRC — Biannual Report

Editor : Antonio Angelini
Editorial Assistant: Paul De Hoe

Published by the
Commission of the European Communities
Directorate General 'Scientific and Technical Information and Information Management'

Bâtiment Jean Monnet
Kirchberg

LUXEMBOURG (Grand Duchy)

Legal notice

Foreword

All years are years of transition. This fact is widely acknowledged in forewords to activity reports. And the years 1974 and 1975 which are covered in this document are no exception. They were the middle years in the execution of the four year programme approved by the Council of Ministers in spring 1973. They were also the years during which the Joint Research Centre (JRC) paved the way for the approval in 1976 of its next four year programme.

A fundamental reorganisation of the JRC was carried out. The first step was to separate the function of the Director General of the JRC from that of the Director General, Ispra Establishment. The Director General, JRC and his staff now sit in Brussels. The Director General of the Ispra Establishment is also the Deputy Director General of the JRC.

A new directorate charged by the Commission with the management of the Ispra Establishment was then appointed, and two major organisational concepts were introduced. One was to separate the tasks of executing the approved programmes from the preparation of future activities. The other was to separate the organization of the work in the specialised departments or divisions, which are centres of excellence in their respective scientific and technical disciplines, from the management of the programmes, with its monitoring of the progress of the work, verification of the relevance of the various actions to their finality and the provision of the interface with the Advisory Committees for Programme Management.

During these two years particular attention has been given to the staff problems which, in the past, have generated serious social tension, and a solution to the most acute difficulties has been accepted by the Commission, for submission as a formal proposal for decision of Council.

In the course of these two years a minor programme revision modifying slightly the balance of effort on some of the objectives, was approved by the Council of Ministers after a lengthy procedural ordeal. Fortunately this did not hinder the execution of the agreed four year programme; the details of the work done and the results obtained are described in this report.

In the meantime, the preparation of the four year programme 1977 – 1980 was undertaken and conducted with the active participation of the scientific and technical members of the staff. About half of the A-grade staff were directly involved in this forward-thinking exercise. External expertise was utilised in the process, which was finalised when programme managers, heads of divisions and directors arbitrated arduous and sometimes painful decisions on programme reorientations.

Whether it be by reorganising the services and adjusting the new organisation to the implementation of the on-going programme, by adopting solutions to long-standing staff problems, or by preparing the decisions for future activities, the two years covered by this report – 1974 and 1975 – have been devoted to making the Ispra Establishment an effective instrument to be put at the disposal of the common needs and policies of research in the European Community.

J.A. Dinkespiler

Deputy Director General of JRC

NIZATION

MISSION
earch Centre

R-GENERAL
Villani

SCIENTIFIC COMMITTEE
2/3 from the Hierarchy
1/3 elected by the scientific and technical personnel
Not elected in 1974 and 1975

ISPRA ESTABLISHMENT
DIRECTOR
J. A. Dinkespiler

GEEL ESTABLISHMENT
DIRECTOR
J. De Meulder

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Mr. Pelser - Chairman

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Mr. Farinelli - Chairman

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Mr. Becker - Chairman

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Mr. De Jonghe - Chairman

TECHNICAL ASSISTANCE TO NUCLEAR POWER PLANT OPERATORS
Mr. Woldringh - Chairman

HYDROGEN
Mr. Berges - Chairman

ENVIRONMENT
Mr. Passino - Chairman

ORGA

COM
Joint Re

DIRECT
S.

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Labrique
Vandamme
De Meester

FRANCE
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Gaussens

R.F. GERMANY
Messrs. *Rembser*
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Kienitz

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Williams

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DIRECTOR
P. Van Węsten

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DIRECTOR
R. Lindner

Part 1

THE RUNNING PROGRAMMES

Presentation of the Projects Directorate

F. H. Newth

In the foreword to this report, reference is made to organizational changes during the period 1974-1975. It is important to give more detail of this, inasmuch as it affects the conduct of the programmes in the Ispra Establishment.

The organization chart in the preceeding report shows all scientific and technical work coming entirely within one directorate. Thus, the managers responsible for the conduct of the programmes were within the same reporting line as the heads of the Scientific divisions. The change which has now been made was to separate the management of the approved programmes from the day-to-day organization of the work of the specialized departments of divisions.

In this report, the organization chart shows three new departments; A B and C concerned with:

Informatics, System Analysis and Information

Engineering Sciences

Physics, Chemistry and Materials Science

Within these departments, each with its own director, the divisions are charged with the duty of maintaining or establishing centres of scientific and technical excellence.

Each project within the overall programme approved by the Council of Ministers has a manager who is responsible for its execution. He has the task of controlling the direction of the work carried out for the project within the Scientific divisions, organizing the resources available within the budget and reporting the results of the work done. These project leaders are united within a projects directorate which is responsible for the overall coordination of the whole programme.

In matrix organization terms, the scientific and technical departments form the vertical lines and the projects – mostly multidisciplinary – form the horizontal lines of the matrix. The nodal points in this structure are the people responsible for supervising the work described in what are called activity sheets. These documents describe the contractual relationship between the project leaders and the division heads.

The project leaders also have the responsibility of providing and maintaining the interface with the Advisory Committees for Programme Management. It is worth recalling that these committees were established in 1969 and were given the task, in their consultative rôle, of contributing to the best execution of the programme considered in detail. They play a key part in the conduct of the programmes and allow a confrontation between points of view of Member States and the Commission.

During 1975, a relatively minor revision of the JRC programme was approved by the Council of Ministers. The effect of this on the Ispra Programme was to authorize a small increase of effort in Reactor Safety and Teledetection of Earth Resources Programmes and to reduce the effort on Nuclear Waste Disposal. The effect of closing Ispra 1 Reactor was also taken into account. The levels of effort in the particular programmes together with the budget are shown in the Table.

In the following chapters, the various projects in the programme are described in detail. It is perhaps convenient to give here a brief introductory statement indicating the type of work done in each project.

Reactor Safety. This falls into two parts: firstly for light water reactors, experiments under depressurization conditions are carried out and the preparation for installing a Blowdown Loop has been made. Mixing studies on fuel subassemblies and fuel coolant studies are made. Secondly for fast reactors, boiling sodium thermohydraulics maximum accident codes and code validation are studied together with investigations of fuel coolant interaction.

Nuclear Waste Disposal. In this project are studied risk analysis for alpha-emitters and their separation from fission products. Basic studies are made on long-term storage, of actinides burning in reactor and monitoring plutonium in solid waste.

Fissile Materials Control. This involves isotope correlation for plutonium control, practical application of non-destructive techniques and development of sealing and identification techniques to reduce inspection effort.

Technical Support to Power Stations. It involves fuel cladding analysis in relation to fuel rod failure and non-destructive tests for reactor components and damaged fuel rods.

Hydrogen Production. Theoretical studies of 23 chemical routes to hydrogen from water using nuclear heat and experimental studies of 19 of these have led to a selection of 5 systems for techno-economic evaluation. Scientific feasibility has been demonstrated and techno-economic feasibility for an industrial process is under study.

New Technologies.

a) Solar Energy. Collector systems for weak and medium energy concentration have been constructed and several high performance collectors and an automatic measuring system have been designed.

b) Materials Recycle. involves computer simulation codes to analyse recycle and substitution effects on recovers of non-ferrous metals.

Protection of the Environment. Remote sensing techniques to measure minute quantities of air pollutants have been developed and Raman-Lidar and IR laser equipment have been constructed. An isotopic lead experiment to measure distribution of lead by automobile exhausts is in process and a computerized data bank for environmental chemical products is now in its pilot phase.

ISPRA PROGRAMME 1973 – 1976*

Programme	Council decision 1973	Council decision 1975		Change in staff numbers from 1973 and 1974
	Budget 1973 - 1976 Muc	Budget 1973 - 1976 Muc	1st line staff	
Reactor Safety	21.10	21.72	122	+ 7
Nuclear Waste Disposal	6.90	5.51	32	– 8
Fissile Material Control	5.40	5.40	27	...
Technical Support and Power Stations	6.10	6.10	23	...
Non-electric application of nuclear energy: Hydrogen product	6.70	7.04	37	...
New Technologies (Solar Energy, Recycling of materials)	3.05	3.05	15	...
Protection of Environment	15.85	15.85	93	...
Remote sensing (Earth resources)	1.05	1.42	8	+ 4
Standards and Reference Materials	6.20	6.20	39	...
Applied Informatics	6.05	6.05	31	...
Information Analysis Services	5.10	5.10	27	...
European Informatics Network (COST 11)	1.00	1.00	4	...
Materials Science and Basic Research in Materials	13.60	13.60	79	...
Technical Evaluations in Support of the Commission	2.00	2.00	12	...
Conceptual Studies on Thermonuclear Fusion Reactors	–	–	12	+ 12
Training and Education	1.45	1.45	10	...
Research under Contract	1.85	1.85	5	...
Ispra Reactor I	2.20	0.90	–	– 15

*) *Including programme revision by Council of Ministers Decision 1975*

Remote Sensing of Earth's Resources. Satellite data have been used to interpret disease and yield in rice crops and poplar trees can be classified. A system has been developed to correct the data for atmospheric attenuation and a number of remote sensing computer programs have been produced.

Standards and Reference Materials. A large number of analytical methods and certifications have been achieved together with the development of absolute physical methods. For the Bureau of Community Materials, analytical methods have been developed for a wide range of products and technical secretariat support is given.

Applied Informatics. This comprises the Eurocopi service to more than 500 organizations in Europe, methods and systems of computing and information science, development of an integrated system for automatic documentation.

Information Analysis Services provides code assessment and shielding data for nuclear organizations. A shielding irradiation facility has been constructed and international shielding programmes are coordinated.

European Informatics Network is work contributing to defining the technical specification of a telecommunication subnetwork and standard basic protocols for communication.

Materials Science. Within this project are studied new effects of thermally induced polarization and identification of radicals in irradiated organic materials by NMR and ESR. Radiation induced self-diffusion in various fcc and bcc metals is determined and high precision temperature control by application of heat pipe concepts has been investigated.

Technical Evaluations in Support of the Commission include codes for study, simulation and optimization of strategies for power plant installation in electric energy production systems and a code for optimizing choice of site.

Training and Education. Fifteen Ispra Courses have been held with a total duration of 25 weeks and 254 participants.

Technical Evaluations in Support of Commission Activities

C. Rinaldini

On the basis of the requests formulated by the various General Directorates of the Commission and of the priorities established by the Committee of General Directions Representatives the studies treated during 1974 and 1975 were the following. They were grouped in two main chapters, energy and transport, and the subjects concerning transport were essentially related to energy problems.

- Energy
  Evaluation of energy policies
  Use of waste heat
  Repeated recycling of nuclear fuel
  Conceptual studies on fusion reactors

- Transport
  Nuclear ship propulsion, shipbuilding and sea transport
  Energy balance of inter-city high speed transportation systems
  Use of methanol

In addition some other studies were done on:

Utilisation of numerical control for the automation of production processes
Advanced electrical components for informatics

The number of man/years involved in these activities during 1974 and 1975 was 12.

Evaluation of Energy Policies

Development of Computer Models

- Simulation of the electric power system

The TOTEM code was developed and enlarged (version 3). This code calculates the consequences of an installation policy, given the overall energy demand and its splitting between various types of station as a function of time.

The energy demand is given in the form of yearly energy production and associated load-duration curve; the variation of the demand during the day and during the year has a considerable effect on the required installed capacity.

The energy produced by the various types of station is given in input, but some freedom is left to the code to reduce the input work and to satisfy a number of constraints: e.g. it can be decided not to install any more stations of a certain type after a given year, and the code calculates the consequent generating capacity of that type taking into account the closing down of the old stations. A more important example concerns the balance of artificial fissile materials: the installation of producers and burners can be calculated by the code in such a way as not to require any imports of that material.

Delay and cost input data are given for the evaluation of demands and expenditures.

The allocation of the power stations in the load diagram is performed according to a priority which allows for age and type of each station.

- Feasibility studies of an energy model

A few alternatives for an energy model were discussed, with the aim to provide a tool for our technical support to the Commission concerning the Target Programme; it was recognized that the study cannot be confined to nuclear-electrical problems; on the contrary, a reasonable assessment must cover all types of production and consumption.

We decided that, at least for a medium-term future, the best course, as with TOTEM (see above), would be to produce an energy-flow model in which the consumption in various sectors is given as a function of time and its distribution over the various types of energy sources and energy carriers is tentatively assigned. That is very much the same attitude as was taken for the development of the USA Reference Energy System.

A simple scheme along these lines, based on the information breakdown provided by the Luxembourg Statistical Office, was programmed (code LABYRINTH).

Contribution to the Community's Target Programme

A large number of evaluations on electrical power installation policies were performed. Particular attention was devoted to the influence of the load-duration curve on the required installed capacity and on the load-factor history of any station. The economic evaluations were centered on the parametrical variations of a number of assumptions, such as interest rate, FBR introduction rate, FBR performance. A useful parameter was found to be the admissible breeder overcost, i.e. the excess of plant cost of the FBR over the LWR that could be accepted as allowing the same overall expenditure over a certain period with and without breeders. This parameter can be used to demonstrate the effects of input variations.

Prospects of HTR Applications

The consequences of numerous hypotheses concerning the penetration of the HTR into the electric power generation system were investigated with the simulation code TOTEM 1.

Here the attention is focused on two questions which were raised at the beginning of 1974:

- Does the introduction of the HTR imply an economic penalty as against a strategy where LRW's and FBR's only are considered?
- Should the low-enrichment HTR be preferred to the thorium HTR because its plutonium production leads to a larger FBR installation rate?

The first question was raised by the UNIPEDE paper:

> Prospects of long-term Development of Fast Breeder Reactors in the European Community of the Nine, March 1974

A comment on that paper was made in our working paper:

> **Remarks on the physical and economical aspects of the development of an electrical power system,** by Graziani et al., November 15, 1974

The same hypotheses concerning the total electric energy demand as a function of time and the fraction allocated to HTR's are made in both papers. The physical and economic characteristics of the plants and of the associated fuel cycle are practically the same, apart from the delay concerning fuel reprocessing for FBR's, which is considerably longer in our assumptions. The most important difference between the two approaches is that in the UNIPEDE paper the plant costs are added and present worth is considered. The difference between the two points of view is remarkably large, even though the same plant cost for all types of station was assumed in our paper.

The following table reports the costs up to the year 2010 (10^9 $):

	LWR (Pu-recycle)	LWR FBR oxide	LWR FBR carbide	LWR+FBR oxide HTR Th	LWR+FBR oxide HTR U
UNIPIDE (fuel cycle)	221.9	198.2	155.5	168.3	206.4
ISPRA (total) -undiscounted	1486	1450	1383	1295	1374
-discounted (10% rate, 1975)	116.1	164.4	159.6	150.2	157.0

These data show that, if a conclusion can be drawn on this basis on such complex matters, it would seem to be in favour of the HTR. The relative variations of the overall cost are, as usual in this type of investigation, very small, but their absolute values are large enough to justify big R&D efforts for the improvement of HTR's.

Waste Heat Utilization from Electric Power Stations

The amount of waste heat released by power stations is increasing relatively faster than consumption under other heads in the energy sector. If the present-day trend of electrification continues, the energy in form of waste heat which will in 1985 be discharged without being used will amount to about 25% of the final energy consumption. Besides wasting energy these discharges will become a serious hazard for the environment.

This twofold problem of waste and pollution can be attacked by three different methods.

a) Combined production of heat and electricity by back-pressure operation of the power plant.
The heat must be produced at suitable temperatures and can be used for distance heating and process heat. In periods with low heat demand (summer) the power plant can be switched over to conventional condensing operation. The main features of this method are the high investment costs and the high relative potential energy savings.

b) Direct use of cooling water from the condensor of a power plant.
Technically most advanced is the use for fish farming and green-houses. Nuclear power plants are especially suitable for those applications. A disadvantage is that the units using the waste heat have to be rather large if all the waste heat of a large (1000 MWe) power station has to be used.

c) Improvement of the heat-to-electricity conversion efficiency by using topping devices. Of the methods discussed, the open-cycle gas turbines and the open-cycle MHD-converter combined with a conventional steam power generator are the most promising for electricity production from fossil fuel.

A simplified calculation, neglecting certain problems which arise from, e.g., investment cost, safety and water scarcity, shows that with 10% of the European waste heat from power plants one can either

cultivate	1.5% of European fish consumption or 10% of the high-quality fish consumption
or heat	27% of existing European green-houses
or satisfy	4.2% of the low-grade heat demand by upgrading the waste heat temperature to about 100°C.

Three methods can be used simultaneously and as long as sufficient waste heat is available they are not competitive. In Figs. 1 to 3 the energy merits of each of them are schematically demonstrated.

Up to now, the main barriers to realization of the above-mentioned solutions have been: 1) high cost, 2) the problem of siting and 3) the big size of units for electric power production, compared to the size of the units for utilization of waste heat. Due to the rapid rise of energy prices, the cost difficulty has become markedly smaller. The siting problem is closely related to nuclear reactor safety and environmental problems, which are constantly evolving.

The construction of a nuclear power plant exclusively for heating will politically not be a good decision, as long as power stations exist which produce only electricity and of which the waste heat is not used. A single-purpose power plant may be economically the cheapest solution, but in terms of energy balance it is wasteful.

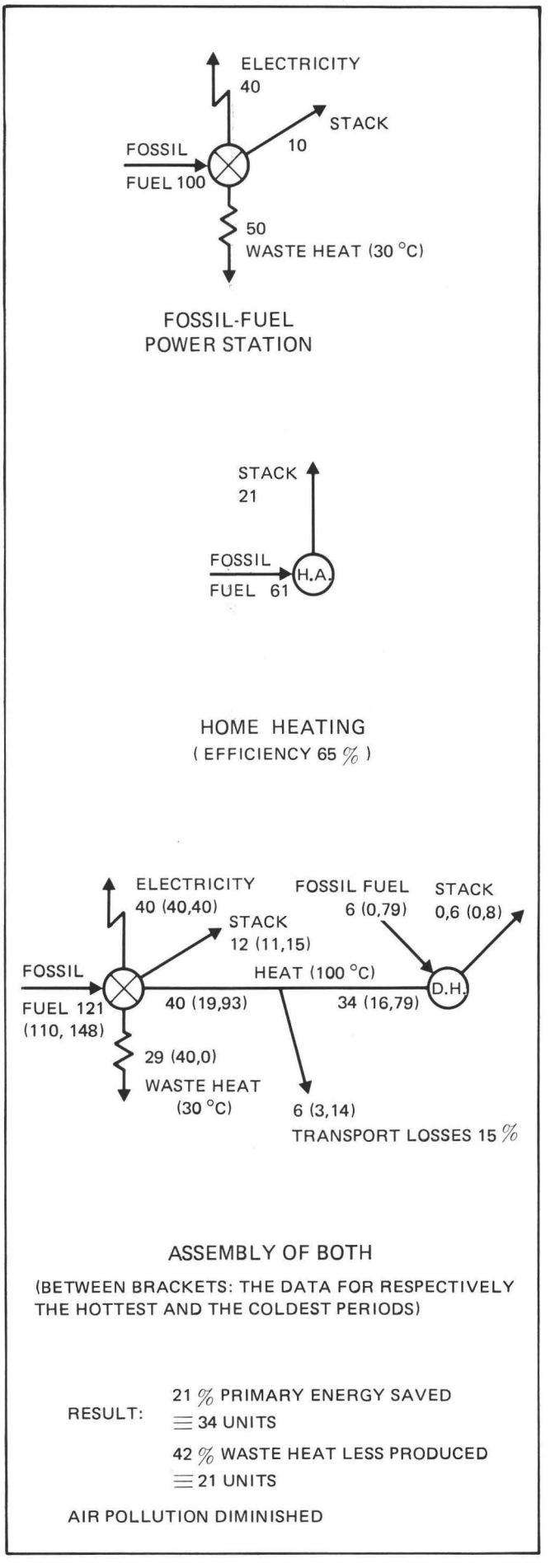
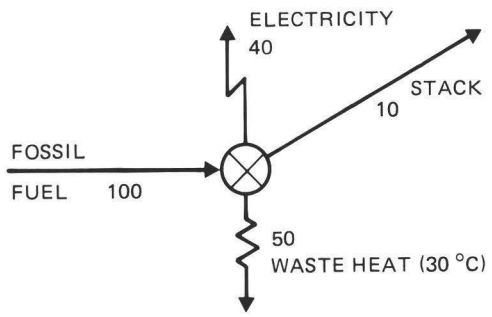
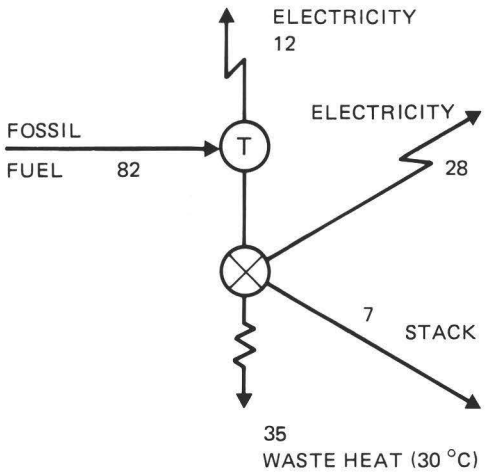


Fig. 1 Average Values over a Full Year of a Distance Heating System Heated by a Fossil-Fuel Power Plant



FOSSIL-FUEL POWER STATION

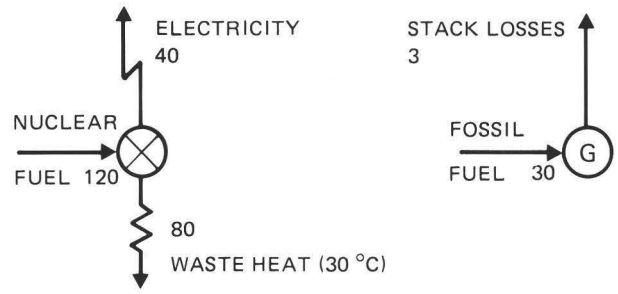


POWER STATION WITH TOPPING DEVICE
OVERALL EFFICIENCY 50 %

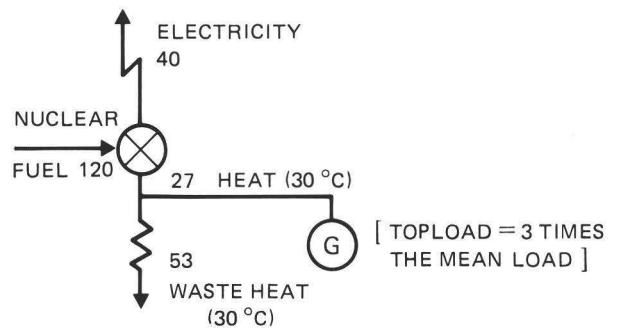
RESULT: 18 % PRIMARY ENERGY SAVED
≡ 18 UNITS
32 % WASTE HEAT LESS PRODUCED
≡ 16 UNITS

AIR POLLUTION DIMINISHED

Fig. 2 Power Station with Topping Device



NUCLEAR PLANT GREENHOUSE



COMBINATION OF BOTH

AVERAGE YEAR RESULT: 20 % PRIMARY ENERGY SAVED
≡ 30 UNITS
30 % WASTE HEAT UTILIZED
≡ 27 UNITS

NO AIR POLLUTION BY STACK LOSSES

Fig. 3 Direct Use of Waste Heat

Technical and Economic Studies on Nuclear Ship Propulsion, Shipbuilding and Sea Transport

Nuclear Ship Propulsion

A dialogue started in 1973 between the Commission and representatives of the C.A.A.C.E. in order to determine what support could be supplied by the Commission to shipowners willing to try an

experiment on a commercial scale. A programme and a preliminary calculation method were prepared in order to assess the penetration of nuclear ships into existing conventional fleets and of nuclear fleets among conventional fleets.

The present situation of the European shipping and shipbuilding industry is complicated by many factors (cost and availability of fuel, freights, transport volume evolution, reopening of Suez Canal, financial problems, etc.), so that it is hard to elaborate forecasts concerning the development of nuclear ship propulsion and it is difficult for the shipowners to take decisions.

Shipbuilding and Sea Transport

A study has been initiated with the aim of analysing the network of the crude oil transport system from the production areas to the EEC countries. The final object of the study is to create a model of the system, suitable for technical and economical evaluations and forecasts.

This model is conceived with a view to subsequent computerization: in fact, the number of parameters to be taken into account is so high and the range of their variations so large (depending also on political and financial factors and the market situation) that a manual calculation is only possible for a limited number of assumptions.

Part 1 of the study deals only with oil shipment between the Persian Gulf and the northern EEC countries; only tankers are considered, to the exclusion of O.B.O.'s and ore/oil carriers. Three main routes are analysed: round trip via Cape, voyage in full load condition via Cape and return in ballast conditions via Suez Canal, round trip via Suez Canal.

The first results concern the present and future surplus of and need for tanker tonnage on the routes considered. The method of calculating the cost of oil transport, under various assumptions, is also outlined.

In a further stage of the study it will also be possible to consider the effects of a gradual introduction of nuclear tankers and product carriers into conventional fleets; the best operating routes and the possible reduction in oil transport costs can be assessed and the consequences for European shipping, shipbuilding and nuclear industries examined.

The study will be continued for other oil routes (Middle East and West African coasts to EEC countries). The resulting model will also be utilised as a part of a European energy model.

Energy Balance of Inter-city High Speed Transportation systems

By high speed, we mean a stabilized maximum cruising speed in the range 250 km/h to 950 km/h: the lower part of this field is filled by the advanced railway system, whilst air transport fills the higher part. In a middle area which overlaps that occupied by the railways and which reaches up to 400-500 km/h are found the non-conventional transportation systems without physical contact with the track, i.e. air-cushion vehicles, attractive Maglev vehicles and repulsive Maglev vehicles. There are also other more advanced systems which will be studied as far as possible.

The distance taken into account for an inter-urban link is generally between 200 and 500 km.

In the energy balance, only the energy required to propel the vehicle will be taken into account leaving out of consideration the energy required for track construction and design and maintenance of vehicles and the energy consumed in the terminals and their outbuildings.

To obtain a basis of comparison between the energy consumption of the different transportation systems, we introduce a dimension called "unit-consumption", i.e. the fuel consumption per transportation unit. In the study, the fuel consumption is expressed in gep (grammes equivalent petrol) whereas the transportation unit is expressed in VK (passenger km), but as this quantity depends on the operating conditions and the vehicle load factor, the transportation unit is also expressed in some cases in SKO, i.e. offered seats per km.

The air transport consumption figures are given in scientific papers and statistics. For example, it is stated that a Boeing 727 on a flight of 400 km has a unit consumption of 60 gep/SKO.

Concerning the ground transportation systems, we need to estimate separately the different factors of vehicle resistance in order to demonstrate the influence of each factor on fuel consumption.

The aerodynamic drag of vehicles, characterized by a very great length in relation to their cross-section, is ill-known and has lately been investigated by full-scale tests on the French TGV in the speed range of 250 - 300 km/h. This drag is present in every transportation system and quickly becomes a dominant factor because it rises as the square of the speed. For example, at 300 km/h, the aerodynamic losses amount to 75% of the resistance of specially streamlined trains like the TGV.

The air-cushion vehicles have a specific drag due to capture of the air feeding the air-cushion. The air must be accelerated from the ambient to the vehicle speed. At 350 km/h this drag amounts to 20% of the total resistance. A second specific drag is due to the power of the fans used to build the pressure in the cushions. The data on these

drags were supplied by the BERTIN company, they are taken from tests done on a preoperational vehicle designed in 1/1 scale, and for this reason must be considered as realistic.

The Maglev (Magnetically Levitated) vehicle resistance is burdened by magnetic drag.

The attractive Maglev suspension system employs electromagnets which are attracted upward towards a pair of overhanging ferrous rails on the guideway. Eddy currents induced by the passing magnet in the guide way rails cause a magnetic drag which increases with speed. At 400 km/h, the magnetic drag and aerodynamic drag have the same magnitude.

The repulsive electrodynamic Maglev suspension system functions only when there is motion between the vehicle and the track. A magnetic field is created on the vehicle by a superconductor coil. When this field passes along a non-ferrous conducting sheet located on the guideway, it creates in it eddy currents which create their own magnetic field. The reaction between these two fields is the basis of the repulsive Maglev suspension. The eddy currents in the conducting sheet create a magnetic drag. This drag attains a peak at a low speed, after which it diminishes as the speed increases. Nevertheless at 400 km/h, the electrodynamic drag is of the same magnitude as the aerodynamic drag.

Other drags must be taken into consideration in accordance with the vehicle support system and the chosen propulsion system. They include rolling resistance, pantograph drag, inertia drag during the transient periods, drags due to the gradient, etc.

The fuel consumption depends on the chosen energy form (liquid fuel or electricity from generating plant) and on the conversion system used to apply the energy to the propulsion system.

The linear motor is the more attractive propulsion system for transportation systems without the track; unfortunately in the present stage of development, this motor is burned with a very low efficiency ($\eta = 0.5$) and power factor ($\cos\varphi = 0.5$).

The drawback here is that the convertor supplying the linear motor is very heavy: indeed the converter weight is proportional to the product $\cos\varphi = \eta$, so that at present it weighs 4 times more than it should. At the present time, the energy balance of the transportation systems which must use this motor is probably excessively worsened by these bad performances. For that reason, the investigation of the latest research executed to find the best linear motor design for high-speed ground transportation systems must be pursued.

By way of conclusion, here are some unit-consumptions computed or extracted from the documentation:

TGV 01 (SNCF) 10 coaches (+ 1 M + 8 C + 1 M)		
electric propulsion:	at 260 km/h	12.5 gep/SKO
	at 300 km/h	15.3 gep/SKO
TGV 01 (SNCF) 7 coaches (1 M + 5 C + 1 M)		
thermal propulsion:	at 260 km/h	16.6-20 gep/SKO
(by gas turbines)	at 300 km/h	21.25-25.6 gep/SKO
AEROTRAIN H 160 (with streamlined air screw)	at 260 km/h	19.5 gep/SKO
AEROTRAIN R 160	at 260 km/h	27.1 gep/SKO
(with turbofan)	at 300 km/h	33.7 gep/SKO
	at 350 km/h	42.9 gep/SKO
Repulsive Maglev with LIM on board	at 300 km/h	40 gep/SKO
(theoretical model)	at 400 km/h	47 gep/SKO
Attractive Maglev with LIM on board	at 300 km/h	24 gep/SKO
(theoretical model)	at 400 km/h	37 gep/SKO
BOEING 727 (Flight of 400 km)		60 gep/SKO

Use of Methanol

The possible utilization of methanol as fuel and as an energy carrier is being investigated. The potential sources for methanol are natural gas, coal, urban waste and agricultural waste. Its possible uses are the following: energy carrier for the transport of natural gas, fuel or additive for motor engines, fuel for turbines for electricity production at peak loads, fuel for fuel-cells, material for chemical synthesis and synthesis of proteins, raw material for hydrogen fabrication. The main obstacles to the penetration of methanol in the fuel market are economic, in competition with the oil products; technical, because a considerable effort is required to increase the present capacity of methanol production units (5000 ton/day); and political, if a substantial increase of coal production is required.

Among the advantages of methanol one can quote the short time needed for new installations to be built (about two years) and the relatively simple technical modifications required by transport engines and by turbines to shift from oil products to methanol. A preliminary evaluation made in the USA showed an estimated market of about 150,000 ton/day in 1985, that is six times the present world production.

Conceptual Studies on Fusion Reactors

G. Casini

Conceptual studies at the JRC Ispra are being pursued in the frame of an action taken by the Advisory Group on Fusion Technology of EEC countries. Ispra is contributing to the assessment of a fusion reactor concept. The work is being carried out in collaboration with CNEN-Frascati and University of Naples.

In 1974 this activity was included among the Technical Evaluations in support of Commission activities. An independent action was started in 1975, in accordance with the revised JRC programme established by the Council of Ministers.

The FINTOR Group (Frascati-Ispra-Naples–Tokamak-Reactor) set up in cooperation between these three laboratories, is making a preliminary assessment of the problems encountered in the design of an experimental TOKAMAK power reactor. The basic features of FINTOR are now as follows. The thermal power output of the plant is of about 100 MW. The plasma and torus radii are 2.25 m and 11.25 m respectively (aspect ratio equal to 5). The average poloidal β is 2.2; the ion and electron temperatures are 25 keV and 21 keV respectively, which corresponds to thermally stable operation of the plasma. The confinement time is 17.6 sec, calculated on the basis of a safety factor of 0.1 with respect to the neoclassical one. The reactor is designed to operate with a single null point, poloidal field superconducting divertor. The magnetic field at the plasma axis is 4.5 tesla; the maximum field in the magnet (D-shaped, Nb-Ti conductors) is 8 tesla. The neutron wall loading is 0.09 MW/m^2. Blanket and magnet shielding are arranged in a modular form, helium cooling and stainless steel structural materials are assumed. Boron carbide powder is the main component of the magnet shielding. The whole reactor, including the magnets, is contained in a vacuum-tight vessel.

The contribution of JRC Ispra to the FINTOR work is concerned with the following areas:

- blanket and shielding nuclear and thermo-mechanical problems,
- tritium production and extraction,
- general reactor layout,
- activation problems
- handling and repairs of reactor components.

The results obtained so far permit one to draw some conclusions concerning the nuclear design of blanket and magnet shielding of an experimental low-power TOKAMAK reactor, in particular:

- convenient breeding ratios can be obtained with 50 cm thick metallic lithium blankets, provided the fraction of structural material is kept low. However, the possibility of replacing liquid lithium by LiAl-alloys mixed with beryllium should be investigated;
- various choices exist as regards reflector material and its position in the blanket;
- boron carbide with an external lead layer represents an attractive way to fulfil the radiation-damage and heat-deposition requirements in the magnet, provided that a sufficient thickness is allowed all around the plasma.

Extraction of tritium by ytthrium appears to be a very attractive solution. Stand-by operation can be foreseen: reprocessing every 160 days corresponds to a tritium build-up of about 3.8 kg.

An estimate of the activation phenomena in FINTOR was carried out on the basis of the nuclear data supplied by Wisconsin (UWMAK-I). This can be summarized as follows:

- after 10 years of operation, at shutdown of the reactor:
  0.7 MCi/MW/h (about 45% in the first wall);
- after 2 years of operation, at shutdown:
  0.5 MCi/MW/h (45% in the first wall);

for a blanket-shielding module a total activation at shutdown of 35×10^3 Ci is expected (25×10^3 Ci after one week). The decreasing of the activation with time after shutdown is slow because it is due largely (40%) to ^{55}Fe which has a half-life of 2.9 years. After 30 months the total activity is one-half of the value at shutdown; after 10 years it becomes 1/25 of the initial value.

Work is also in progress to define the main problems related to the mechanical layout, stress analysis behaviour of the blanket modules, and overall design of the reactor.

Research under Contract

A. Angelini

The JRC activities at Ispra include various types of contracts with third parties. These are:

- **Contracts carried out for third parties.** The work carried out within the context of these contracts is in no way related to the research programmes of the JRC. The work is requested by outsiders on the basis of the competence or equipment available within the JRC. The contractors assume entire responsibility for the costs of material used and staff employed on this work.

- **Collaboration contracts.** These involve activities which are related to programmes in progress and are also of interest to external institutions. These activities are normally carried out within the JRC, and the costs are borne partially by the JRC and partially by the interested third parties.

- **Programme contracts.** These are activities involving exclusively JRC programmes, and the work is performed outside the centre (in cases where the required apparatus is not available within the centre). The costs are borne entirely by the programmes concerned.

In parallel to these contractual activities, there is also a "Research under contract" programme.

The aims of this programme are: to carry out special tests on apparatus patented at Ispra (at the request of D.G. XIII); to organize stands at scientific exhibitions; and to develop ideas and processes which have a good chance of leading to contracts (or for which contracts are already being drawn up).

The specific budget of this programme is about 50,000 AU/year and the personnel allocated is 5 man years working mostly with materials and equipment already available.

During 1974-1975 research activity in this programme involved the following subjects:

- Development of MET-X seal and weldings
- Development of a patented gas depurator
- Systems Reliability
- Application of X-ray diffractometry to lattice parameters
- Technical support for the preparation of stands at exhibitions
- Development of ultrasonic instrumentation
- Studies on the hydrogen diffusion mechanism.

In order to give some idea of what the potential contractual fall-out of this type of activity might be, a list of the contracts currently being discharged at the JRC at the request of external institutions is given below.

List of contracts

Contract No.	Contract object	Contractor	Expiration	Financial contribution of the contractor (u.a.)
036-71-PIHOB	Examen tenue maquette cuve réacteur SNR	Belgonucléaire	31.12.74	15,620
055-72-PIHOI	Fabrication de détecteurs flux neutronique autogénérateur	Corradi	31.12.75	51,760
065-72-PIHOI	Méthodes de contrôle fabrication éléments combustibles	C.N.E.N.	30.7.75	90,000
075-72-PIHOI	Mesures de définition de produits manufacturés en Zircaloy	C.I.S.E.	30.6.74	14,600
080-72-PIHOB	Examen post-irradiatoire sur échantillons combustibles. Projet RHT-CEN.BN	CEN - MOL	31.12.76	21,513
085-72-PIHOI	Examen post-irradiatoire du combustible	E.N.E.L.	31.12.74	80,000
089-72-PIHOI	Mesures de body-counter	Sté COREN	21.2.74	200
106-73-PIHOI	Mise à disposition four Degussa	SAES GETTERS	15.5.76	46,600
110-73-PIHOEX	Safeguards	I.A.E.A.Vienne	30.11.75	9,500

List of contracts • *continued*

Contract No.	Contract object	Contractor	Expiration	Financial contribution of the contractor (u.a.)
115-73-PIHOF	Etude de frottement	Sté FERODO	30.6.75	13,504
117-73-PIHOUK	Analyses de structure interactions entre métaux et NTR cooland gases	U.K.A.E.A.	30.10.75	12,000
119-73-PIHOI	Mesures et évaluation contamination interne U-235 dans les poumons	Fabricazioni Meccaniche Nucl.	31.12.74	4,000
124-73-PIHOI	Elaboration de données météorologiques relevées au Centre EUREX de Saluggia	CNEN EUREX	30.4.74	4,800
125-73-PIHOI	Cellules cryogéniques pour mesures sur les gaz	Ist.Metrologia "G.Colonnetti" C.N.R.-Turin	26.3.74	1,440
126-73-PIHOI	Cryostats pour réalisation de points triples des gaz en vue réalisation références pour échelle internationale des températures	Ist.Metrologia "G.Colonnetti" C.N.R.-Turin	1.9.74	2,880
129-73-PIHOI	Dimensionamento schermi reattore PEC e sviluppo tecniche di schermaggio dei reattori veloci	C.N.E.N.	31.5.76	17,880
130-73-PIHOI	Etude et développement d'un prototype de four isothermique à heat-pipe	Ist.Metrologia "G.Colonnetti" C.N.R.-Turin	30.6.75	3,200
131-73-PIHOI	Locazione elementi combustibili ECO	C.N.E.N.	31.12.80	23,000
132-73-PIHOI	Soudures de composants en niobium pour cavités RF	Ist.Naz.Fisica Nucleare-Genova		880
133-73-PIHOI	Soudure de deux chemises pour canaux Cart 2	C.I.S.E.	6.6.74	6,996
134-73-PIHOCOM	Fabrication appareil de vérification d'identité de sceaux pour méthode ultrasonore	Contrôle de Sécurité-Luxembourg	31.12.74	9,000
135-73-PIHOI	Fornitura serbatoio a pressione	FIAT	Avril 1974	480
136-73-PIHOUK	Adaptation du Code Costanza pour Dragon	UKAEA DRAGON	30.9.75	19,140
141-73-PIHOI	Prove di scoppio in Betulla per programma CIRENE	C.N.E.N.	31.12.77	24,000
142-73-PIHOI	Vendita di materiale ECO	C.N.E.N.	15.4.74	5,760
143-73-PIHOD	Blow-down	B.M.F.T. Bonn	30.11.77	3,811,150
144-74-PIHOI	Elaboration annuaire météorologique du site EUREX à Saluggia	CNEN-EUREX	30.5.75	4,800
146-74-PIHOI	Stoccaggio materiale	SIEMENS	30.11.74	1,920
147-74-PIHOI	Determinazione di piombo e cadmio su pezzi ceramica	Ceramiche Revelli	7.3.74	112
148-74-PIHOI	Misure per contaminazione interna	Fabbricazioni Nucleari Genova	18.12.74	4,000
151-74-PIHOCOM	Vasque d'identification de sceaux MTR (vasque + capteur)	Contrôle de Sécurité-Luxembourg	31.3.74	1,000
152-74-PIHOCOM	Fabrication et fourniture de 400 sceaux "usual uses" en SAP	Contrôle de Sécurité-Luxembourg	31.7.74	4,400
154-74-PIHOI	Messa a punto di un programma di calcolo	C.S.M.-Rome	31.4.74	4,000
156-74-PIHOD	Calcul de la cuve Neckarwestreim	T.U.V.-Stuttgart	31.9.74	5,000
157-74-PIHOI	Smaltimento residui radioattivi	SNAM PROGETTI	30.11.74	320
159-74-PIHOI	Prove di decontaminazione su materiali metallici	C.I.S.E.	Mars 1975	1,000
160-74-PIHOI	Stoccaggio definitivo refiuti radioattivi liquidi e solidi	Agip Nucleare	31.12.74	400
162-74-PIHON	Etude paramètres de soudure par magnésoudage de 2 tubes en alliage Al-Si-Mg	R.C.N.-Petten	30.4.75	4,000
165-74-PIHOI	Stoccaggio materiale radioattivo	T.S.R. Castelbolognese	31.7.74	480
166-74-PIHOI	Saldature BE di otto spezzoni di Zircaloy	C.I.S.E.	30.9.74	760
168-74-PIHOI	Misure di body counter	Sté.COREN	8.4.74	220
169-74-PIHOI	Saldature a fascio elettronico su due valvole	Grandi Motori	15.9.74	640

List of contracts • *continued*

Contract No.	Contract object	Contractor	Expiration	Financial contribution of the contractor (u.a.)
171-74-PIHOF	Fourniture d'appareillage électronique pour physique neutronique	Inst.Max von Lauer et Paul Langevin-Grenoble	30.6.75	11,523
173-74-PIHOI	Smaltimento rifiuti liquidi radioattivi	SNAM PROGETTI	31.10.74	145
174-74-PIHOCOM	Fourniture de pinces de pose et d'extraction de sceaux sur éléments frais MTR	Contrôle de Sécurité-Luxembourg	30.6.75	2,000
175-74-PIHOI	Misure body counter	Progettazioni Meccaniche Nucleari	31.12.75	4,000
178-74-PIHOI	Controlli con W.B.C. (body counter)	C.I.S.E.	31.12.75	300
179-74-PIHOI	Assistenza agli studi di sicurezza e licensing per CIRENE	Sté.NIRA	31.8.75	24,000
180-74-PIHOI	Assistance technique dans la projectation d'un appareillage pour spectrométrie gamma	CNEN-EUREX	31.12.75	1,500
182-75-PIHOI	Stoccaggio materiale radioattivo	SNAM PROGETTI	31.12.75	1,040
183-75-PIHON	Magnesoudage des tubes Al-Si-Mg	R.C.N.-Petten	30.6.76	10,000
184-75-PIHOI	Saldature per bombardamento elettronico (E.B.)	C.I.S.E.	31.12.76	22,000
186-75-PIHOI	Fabbricazione 2 canali Zr	C.I.S.E.	31.3.76	25,200
187-75-PIHOI	Prove decontaminabilità di vernici	Davidsen	31.3.76	440
190-75-PIHOC	Fourniture de pièces de rechange de gamma scanning	Comm. CSL Luxembourg	31.3.76	480
193-75-PIHOC	Fourniture de pièces de pose	Comm. CSL Luxembourg	31.3.76	3,000
194-75-PIHOC	Fourniture de barrettes de plexiglas	Comm. CSL Luxembourg	31.3.76	3,000
199-75-PIHOI	Misure sanitarie	Progettazione Meccaniche Nucleari	31.12.76	6,400
201-75-PIHON	Etudes de soudures spéciales	R.C.N.	31.12.76	26,000
202-75-PIHOCOM	Fourniture de pièces d'extraction à distance	C.S.L.-Luxembourg	30.4.76	9,000
204-75-PIHOI	Stoccaggio residui radioattivi	Prodotti Gianni	31.12.76	5,230
205-75-PIHOI	Stoccaggio residui radioattivi	PALMOLIVE	31.3.76	640

Technical Support to Nuclear Power Stations

N. Cadelli, M. Bresesti

The Technical Support to Nuclear Power Stations programme was approved by the Council of Ministers on February 1973. During 1973 it was not possible to utilize all the resources allocated to the programme owing partly to the lack of available specialized personnel and partly to the fact that the majority of the items in the programme had to be discussed with the utilities in order to match the programme with the real needs and to obtain material, especially fuel elements, to be investigated.

Apart from the Water Chemistry action which, advocated by the Water Chemistry Working Group, has been in progress since 1971, all other activities had to be set up in cooperation with the nuclear power stations already in operation. It appeared reasonable to begin the research on light water reactors, which account for the largest number of power stations in operation or under construction.

After discussions with the utilities the list of subjects for action was defined as follows:

- Water Chemistry
- Post-Irradiation Examinations
  - Fuel Rod Analysis
  - Bench Mark Experiments
- Quality Control of Reactor Components
- Statistical Evaluation of Non-Uniform Corrosion in High Temperature Water
- Decontamination Studies

Action	Manpower (man/years)		Budget (u.a.)	
	1974	1975	1974	1975
Water chemistry	5	4.5	27,000	43,000
Post-irradiation examinations				
- Fuel rod analysis *	2	3	117,000	90,000
- Bench mark experiments	5	5	60,000	78,000
Quality control of reactor components	6	6.5	45,000	63,000
Statistical evaluation of non-uniform corrosion in high temperature water	2	2.5	11,000	31,000
Decontamination studies	–	–	–	–
TOTAL	20	21.5	260,000	305,000

*) *7 people of the Hot Laboratory (LMA) are also charged to this action.*

A breakdown of the budget (excluding personnel charges) and manpower (first line people) allocated to the different subjects are given in the table for the years 1974-1975.

Water Chemistry

The studies concern the phenomena of mass transport in primary circuits of light water reactors, i.e. generation, transport and deposition of corrosion products.

Mass transport can cause difficulties in reactor operations in various ways, such as activity accumulation, increased pressure drops in various circuit sections or overheating due to decreased heat exchange, etc. The studies are conducted along four principal lines:

Corrosion Product Release: The aim of this study is to investigate in a test loop the chemical and physical nature and quantity of corrosion products released from stainless steel surfaces in high-temperature water circuits and the influence of the variation of certain parameters (water impurities, additives and flow speed).

In the first half of 1974 the experiments at low flow speed with pure water and the tests of the on-line Coulter counter were completed, and the second half of the same year we began to prepare experiments on corrosion-product release at high flow speed. The circulation pump did not achieve the performances required and several modifications were necessary. This pump problem was not solved until late in 1975.

The programme of experiments to be carried out in the test loop was discussed at the meeting of the Water Chemistry Working Group held at Ispra in May 1975. The time necessary to carry out the programme was estimated by the working group members as about two and a half years.

Corrosion Product Deposition. The aim of this study is to evaluate in a test loop the influence of the variation of certain parameters (water impurities, additives and flow speed) on the deposition of stainless steel corrosion products in high-temperature water circuits.

Some heavy components of the corrosion-product deposition circuit were fabricated during 1974. The construction of this circuit was held up by the technical problems of the circulation pump.

Electrokinetic Studies. The aim of this study is to verify, by means of surface capacity measurements, the results of theoretical investigations on solid particle depositions. The assembling of the instrument was completed in the first part of 1974. A first set of electrokinetic measurements showed that a more precise electrical instrument is necessary. A new instrument has therefore been ordered and the electrokinetic measurements will be repeated during 1976.

Analysis of Corrosion Products from Power Stations. Solid corrosion products suspended in primary circuit water of the nuclear power stations of the Community were collected and analysed for their chemical and physical properties and especially for their crystallographic structure which is normally not submitted to routine analysis.

Post-Irradiation Examinations

Fuel Rod Analysis

The aim of this work, which is carried out in the Hot Laboratory (LMA) of the Ispra Establishment, is to study the mechanism responsible for fuel rod failure, by means of experimental examination of defective fuel rods.

The measurements carried out on the fuel rods are essentially the following:

- Optical inspection of fuel rod cladding
- Determination of the diameter variation of the cladding
- Detailed determination of the gamma activity profile
- Metallographic examination of cladding and fuel material
- Determination of the fuel density
- Determination of the ultimate tensile strength for a portion of cladding and examination of the mode of fracture
- Dimensional measurements of the irradiated fuel on the basis of data derived from gamma scanning.

After the approval by the Council of Ministers of the programme on Technical Support to Power Stations, discussions were immediately started with power-plant operators with the object of obtaining fuel rods for post-irradiation examinations at Ispra. These discussions and the organizing of the fuel transport to Ispra took quite a long time.

Thus, up to the end of 1974, the experimental work was limited to the analysis of the only available fuel, i.e. fuel rods, with stainless steel cladding, from the Trino Vercellese power station. In this stock of fuel no failed rods were present. On the Trino Vercellese fuel the following examinations were carried out: non-destructive gamma measurements including burnup determinations and measurement of pellet length, metallographic and optical inspection of the fuel rods, and tensile tests on fuel cladding.

At the end of 1974 and beginning of 1975 the following fuels were transported to Ispra for examination:

- 10 fuel rods from the Gundremmingen power station
- 4 fuel rods from the Garigliano power station
- 6 fuel rods from the Obrigheim power station
- 5 fuel rods irradiated by CISE in the ESSOR reactor.

During 1975 we examined the fuel rods from Gundremmingen (Zircaloy cladding) and CISE (Zircaloy cladding).

The examinations of the Gundremmingen rods began with a series of non-destructive tests – optical and photographic examination of the fuel rod cladding, determination of the gamma activity profile of the rod and determination of the diameter variation profile.

On the basis of the experimental results obtained in the non-destructive tests, the rods to be subjected to destructive tests were selected. The destructive analyses of the selected rods were designed to collect as many data as possible of use in characterizing the failure mechanism.

The following analyses have been started:

- Determination of the crud thickness and its variation along the rods;
- Examination of the inner surface of the cladding to investigate possible chemical and mechanical fuel-cladding interactions;
- Metallographic examination of sections of rods and sections of cladding
- Determination by gamma spectrometry of the diametral distribution of some solid fission products to detect their possible migration.

During 1975 only the non-destructive analyses have been carried out on the 5 rods of CISE.

Due to the difficulties to have available the flask of CEA required for the transportation of fuel rods, the construction of a new flask has been decided. The order has been given to the supplier (Robatel-SLPI) on February 1975. The flask construction is expected to be completed for middle 1976.

Bench Mark Experiments

The aim of the Bench Mark Experiments is the production of a set of reference data on burnup, isotopic compositions and cross section ratios to be utilized for the control of nuclear code calcula-

tions. The experiments are carried out on fuels irradiated in an asymptotic neutron spectrum. The activity in this field consists of:

- Determination of burnup and isotopic compositions in irradiated fuels by means of radiochemical analysis
- Analysis of the experimental data in terms of cross-section ratios and neutron spectrum by means of unfolding codes
- Collection of the necessary information from the utilities for each experiment, so that other fuel management groups may use these data for checking their codes
- Calculation of one or more typical clean experiments by different fuel management groups for intercomparison of cross-section sets and codes used.

The final goal is to create a pool of clean experiments with the necessary information so that fuel management groups may test their codes and cross-section sets.

Experimental Work

During 1974-75 the analyses of the fuel discharged from the Trino Vercellese reactor after the second irradiation cycle were completed. The fuel assembly was dismantled in the pool of the ESSOR reactor and 7 rods were removed. In the ADECO laboratory of the ESSOR reactor each rod was cut into three pieces about 1 m long. The fuel was transfered to the LMA laboratory where gamma scanning measurements were carried out and the fuel cross-sections were prepared.

The fuel cross-sections were delivered to the analytical laboratories of the Ispra and Karlsruhe Establishments where radiochemical treatments and alpha, gamma and mass spectrometry measurements were carried out.

The following data were determined:

- burnup from ^{137}Cs, ^{148}Nd and heavy isotopes
- uranium isotopes (235, 236, 238)
- plutonium isotopes (236, 238, 239, 240, 241, 242)
- americium isotopes (241, 242, 243)
- curium isotopes (242, 244)
- krypton and xenon isotopes
- ^{134}Cs, ^{154}Eu, ^{144}Ce, ^{106}Ru

23 fuel samples with burnup ranging from 16,000 to 26,000 MWD/MTU were analysed.

In the latter part of 1975 the analyses of the fuel irradiated in the Gundremmingen reactor were started. 16 fuel samples will be analysed in the Ispra and Karlsruhe laboratories.

During 1976 the Obrigheim reactor fuel will be analysed.

Theoretical Analysis

During 1974 the codes required for the analyses of the experimental data in terms of cross-section ratios and neutron spectra were developed. The theoretical analysis was applied first to experimental data determined on the fuel discharged from the Trino Vercellese reactor after the first irradiation cycle. These data had been determined in 1972 under an ENEL-Euratom Research Contract. In the second part of 1975 we began the theoretical analysis on the experimental data of the Trino-2 fuel.

Quality Control of Reactor Components

Our work in this field was directed towards developing and improving the non-destructive techniques for the testing of irradiated fuel rods or other components of a nuclear power station. The activity of 1974-75 covered the following items:

Characterization of the Ultrasonic Instrumentation

The methodology of the characterization was studied. An apparatus was installed to be used not only for characterizing probes but also for correcting them where possible. Several transducers to be used for fuel examination were characterized. One transducer for vessel examination (DOEL reactor, Belgium) was exhaustively characterized on request. A new apparatus was installed to increase the possibilities of the Schlieren normalization bench, both in power and in capacity to examine long-focused transducers.

Fabrication of Reference Defects for Calibration of Ultrasonic Apparatus

Well-defined and reproducible defects are required for the calibration of ultrasonic apparatus. We prepared reference defects by combining and improving three classical methods, electroerosion, ultrasonic and punch techniques.

Testing of LWR Fuel Bundles by Ultrasonics

The initial aim of this work was to detect water in irradiated fuel pins without dismantling the fuel bundle. The parameters of the method were defined in a cold laboratory (type of transducer, definition of the detection method). However, information given by plant operators indicated that the test for presence of water is not sufficient for the detection of failed rods in the bundle.

Instead of limiting the technical study to this first aim, we now have a project under way for testing a larger part of the fuel rod with the following purposes:

- detection of water
- measurement of the wall thickness
- detection of cracks.

Neutron Radiography

Neutron radiography is employed to evaluate the quantity of hydrogen absorbed by getters to be used in nuclear fuel pins. Experiments were carried out during 1975 in the neutron radiography facilities of the reactors BR2, Mol (Belgium), Pegy, Cadarache (France), and Siloette, Grenoble (France). The analyses of the neutron radiographs of calibrated samples (hydrided at levels of 10-10,000 ppm) yielded a calibration curve giving the correlation between density on the photogram and hydrogen concentration.

Statistical Evaluation of Non-Uniform Corrosion in High-Temperature Water

The statistical evaluation of stress corrosion in water has been proposed as a new approach to the study of this type of damage. Stress corrosion is already well studied and in many respects quite well understood, but its introduction as a design parameter has not been attempted successfully so far, mainly because the damage is not easily quantifiable. If the failure rates due to stress corrosion were known, preventive maintenance and failure prevention would then be feasible.

Consequently the purpose of the present programme is to evaluate the practical experimental values of the expected life of equipment subject to stress corrosion. This approach originated from the very nature of failures: they are statistical events, to which the appropriate statistical treatment may be applied to obtain the parameters necessary for such an evaluation.

On the reasonable basis of randomness of the distribution of initial cracks (due to fabrication or other causes) and of the overall environment, the process of crack growth due to stress corrosion will be random. The weakest region will be the controlling factor in rupture, so that the whole process may be analysed and quantified by means of the statistics of the extreme values, correlating the residual life of stress-corroded samples with crack length and distribution.

In this programme we propose to determine this correlation experimentally and at the same time to develop the theoretical background for the analysis of the experimental data.

The necessary measurements and equipment have had to be developed as well.

Our intention was to do a first orientative series of measurements in boiling $MgCl_2$ solutions, for a quick assessment of the feasibility of the work. The main body of the experiments was to be done in a high-temperature water environment in conditions similar to those of nuclear power stations.

This programme was started in 1974 with very limited funds and manpower, so that relatively little experimental work has been done up to now.

During the first year the following preliminary work was done:

a) first theoretical development of the proposed approach,
b) conceptual choice of the experimental methods and apparatus,
c) choice of the type of samples, taking into account the standardisation of the samples for mechanical testing and for the studies of fracture mechanics,
d) clamp design and fabrication for $MgCl_2$ testing machines and autoclaves,
e) design of the modifications and design of the special sample-holders for the existing high-temperature autoclaves,
f) autoclave modification; fabrication of special parts,
g) development of methods of counting the fissures due to stress corrosion and of preparing post-corrosion samples,
h) preliminary measurements in boiling $MgCl_2$ (153°C) solution on AISI 304 samples.

Decontamination Studies

The introduction of the action "Decontamination Study of Primary Circuit Components" in the programme "Technical Support to Nuclear Power Station" was suggested by the "Water Chemistry Working Group".

The decontamination study may be a valid subject of research to be developed in the framework of a new pluriannual programme as extension of the present one.

Therefore it was considered useful to start a small preliminary action in the framework of the present programme, in order to achieve a better knowledge of the problem, to collect information from the interested power stations and to set up the techniques of analysis on samples taken from the primary circuit components.

Some samples have been collected and transported to Ispra from the Obrigheim power station. A tentative of characterization of the contamination deposit will be done by optical inspection, metallographic examination and fluorescent analysis, if possible (depending on the thickness of the deposit).

Nuclear Waste Disposal

A. Angelini

The research work has been organized according to the following table (average values 1974 ÷ 1975):

Actions/studies	Manpower (man/years)	Budget (u.a.)
1. Chemical studies		
- waste hazard evaluation	1.8	–
- pyrochemical methods	3.5	10,000
- separation of actinides	8.2	56,000
- radiation damage in glass	3.0	14,000
2. Physical studies		
- assessment studies	3.0	3,000
- cross-section measurement	5.0	45,000
- monitoring of actinides	2.5	17,000
3. Data evaluation	3.0	5,000
TOTAL	30.0	150,000

Chemical Studies

Waste Hazard Evaluation

In order to evaluate the long-term α-hazard of radioactive wastes, with a view to identifying areas in which further research is needed, we started our study by taking into account the vitrified high-activity waste (HAW) arising from spent nuclear fuel reprocessing.

In this study we calculated the concentration of α-emitters in HAW, their decay and daughter-product build-up down to 10^6 years. We attempted to evaluate the hazard of waste disposal in a geological formation by the "barriers" approach. Four barriers were identified:

- quality of the segregation afforded by the geological formation,
- stability, chemical and physical, of vitrified waste,
- retention of actinides by the surrounding environment,
- ecological distribution patterns of actinides.

As a first approach, a model for waste hazard evaluation was defined, in order to obtain levels of release of α-emitters and their environmental distribution.

We defined very schematically, a system constituted by the following elements:

- a deep subterranean repository of radioactive wastes,
- a geological barrier,
- a uniform one-dimensional soil column,
- a body of surface water crossing a populated region.

The release from the repository was assumed to be caused by failure of isolation from groundwater, which was shown to be the most likely mechanism leading to the transport of activity to the biosphere. The probability of occurrence of this event was not evalauted, since our intention was to evaluate what would happen if the geological isolation should fail.

An extreme case, due to a particular geological situation, is given by "no soil retention", which has been assumed in the present study, as being the most conservative.

After migrating through the soil column, the radionuclides are assumed to enter a surface water stream, where their concentration depends on their release rate and on the flow rate of the river.

The entry of actinides into the food chain of man is due to the use of such contaminated water as for drinking and for agricultural purposes. To calculate the concentration in soil, some assumptions had to be made, e.g.:

- the actinides contained in the irrigation water are completely adsorbed in the upper layer of soil, within a depth of 10 cm.
- the irrigation rate is of the order of 1 m^3/m^2 per year.
- the accumulation time was fixed as 50 years.

In order to do a numerical application, some quantities had to be defined; the first of these, required in order to calculate the rate of release from the geologic repository, were

- quantity of waste
- actinide content
- time of failure
- dissolution times.

The data obtained were compared with the average concentration of ^{226} Ra in soil.

The Annual Intake to Man was calculated from drinking water, vegetables and meat; a total of 0.24

μCi/yr was obtained, resulting mainly from water and from vegetables. It is about one-tenth of the Limit of Annual Intake established by IAEA.

Pyrochemical Methods

During 1975 the pyrochemical programme was pursued according to the schedule suggested in the document "Layout of the Research work" prepared for the 3rd Meeting of the ACMP on Nuclear Waste Disposal (October 1974).

- Choice of the nitrate melt

Experiments were performed using the binary eutectic of Ca and K nitrates (melting point 146°C). This kind of melt bath does not allow good results during the first step of the process, for the UO_2 - PuO_2 (15%) pellets in solid solution form (coprecipitated) are quickly pulverized in this melt at 480°C, but the fuel material is not oxidized at the higher valence state. As a consequence, in the following step of dissolution the uranium and plutonium do not react completely with HNO_3 vapour. On the contrary, as reported in the previous progress report, the UO_2 and UO_2 - PuO_2 in mechanical mixture can be dissolved easily by this method.

In the case of a solid solution of mixed oxides it is considered that the treatment with calcium and potassium nitrates can be used to recover plutonium from the residues of the nitric acid dissolver used at the reprocessing plant; the solid solution could be dissolved by the nitric acid while the residue could be rendered soluble by this treatment.

- Volatile fission products: extraction and splitting

An experimental apparatus was developed for gaseous phase treatment. The gas phase, evolving from an oxidative breakdown process, consists of: N_2, O_2, NO, NO_X coming from the nitrate melt, and H_3O, Kr, Xe, coming from the irradiated fuel.

Cold tests were performed to see whether the non-radioactive gases could be split prior to the absorption of Kr, Xe and tritiated water. By means of a copper-filled furnace, kept at 500°C, the nitrogen oxides can be dissociated and the resulting oxygen fixed as CuO. The water vapour passes through the copper furnace without absorption and can be fixed by a molecular sieve trap. The final separating of N_2, Kr and Xe is to be done by cryogenic distillation. The results obtained so far confirm this flow-sheet and work is still in progress to determine the best working parameters for the system.

The analysis of the gas phase before and after the copper furnace was performed by mass spectrometry.

- Solvent extraction from molten nitrates

Exploratory experiments in solvent extraction of $UO_2(NO_3)_2$ and $PuO_2(NO_3)_2$ from molten nitrates were performed during the year under report. The eutectic mixture of Li, Na and K nitrates was used at 150°C; the U and Pu contents in the melt were 1.1 and 1.2 w% respectively. Two cm^3 of the organic phase, constituted by 9% TBP dissolved in a mixture of terphenyls (HB40 Progil), were placed in contact with 2 cm^3 of molten salts.

In the tests performed with uranium alone, an extraction of 97% is obtained in one minute of contact. The stripping of uranium from the organic phase was tested with 1M Na_2CO_3 solution at 25°C, yielding:

85% stripped out by one one-minute contact
98% stripped out by two one-minute contacts.

The tests with plutonium are still in progress; the preliminary results indicate an extraction value of 84% with one one-minute contact and a back extraction of 70% with 3M Na_2CO_3 solution.

- Decontamination of molten salts

The nitrate decontamination experiments were continued with special attention to cesium which is the most important contaminant in the alkaline nitrate melt. For this purpose, several inorganic absorbents were tested.

Batch absorption tests were performed at 150 and 200°C with Li, Na, K nitrate eutectic traced with ^{137}Cs and the various adsorbents (previously equilibrated with pure salt solvent). The results of these decontamination experiments were discouraging since no significant K_D was found for Cs.

- Silicotitanate glasses

The study of the transformation of nitrates into silicotitanates, so that they may be stored for a long time, is being carried out in collaboration with AGIP Nucleare. As reported in the 1974 report, by high-temperature reaction with SiO_2 and TiO_2 the nitrates are transformed into different silicotitanates following the reaction:

$$2MeNO_3 + a\,SiO_2 + b\,TiO_2 \longrightarrow$$
$$\longrightarrow Me_2O \cdot a\,SiO_2 \cdot b\,TiO_2 + 2NO_2 + 1/2\ O_2$$

The solubility in water and the leaching rate of these compounds was very promising, so that during 1975 further leaching tests were performed with silicotitanate glasses produced in the presence of a synthetic mixture of fission-product oxides.

Separation of Actinides

- Solvent extraction

Different types of organic extractants were experimentally investigated for waste-partitioning. A comparable study was also carried out on an organophosphorous compound, di(2-ethylhexyl)

phosphoric acid (HDEHP), which is an excellent candidate for this partitioning task. In fact, it has been extensively studied in the past and used for nuclear purposes. Many detailed investigations have proved the usefulness of HDEHP for recovery of fission products and transplutonic elements and removal of actinides from waste solutions. Whether, however, it can solve the problem of waste partitioning still has to be demonstrated. The most difficult problem posed by the use of HDEHP is that of establishing a method of stripping fission products such as Zr, Mo and noble metals from the loaded solvent so that it can be recycled. Experimental studies were therefore initiated and developed during 1975 in order to discover the best conditions for stripping out the metal ions extracted by HDEHP from highly acidic simulated HAW solution (4.8 M HNO_3).

- Precipitation and ion exchange

This work concerns the chemical separation of actinides (essentially Pu, Am, Cm) from high-activity waste (HAW) derived from PUREX reprocessing. Neither products commercially available nor others previously developed by our laboratory are really suitable for complete actinide recovery from HAW. A few experiments were done on the use of solid salts of oxalic and hydrofluoric acid, which can displace the rare earths and the actinides from low acidic solutions to form more insoluble oxalates or fluorides.

The automated equipment for equilibrium studies was completed and tested. The dimensions of the equipment are such that it can be easily installed in a glove-box for actinide research.

Future applications will probably deal preferentially with the study of actinide mobility in soils.

Research is continuing on the precipitation of rare earths and actinides (OXAL process) from simulated waste solutions. It was assumed that 1 ton of fuel gives rise to 5000 litres of waste (W 1), which is successively concentrated 10 times (W 10) for final storage. Experiments are planned on the two extreme conditions W 10 and W 1, with and without phosphate ions (from degradation of TBP = ~0.5 g/l). At present all efforts are concentrated on W 1.

Denitration is carried out by slow addition of the waste solution to boiling formic acid. No difficulty was found in reaching the pH required for a good precipitation of oxalates (pH = 1-2). A final pH adjustment by means of 5 M NaOH is done after oxalic acid addition.

From phosphate-free W 1 solutions the precipitation of rare earth oxalates was good. Americium was completely precipitated, although ~ 1%Pu was left in solution.

A slight precipitate was formed during denitration of W 1 and was dissolved by the addition of controlled amounts of HF in order to complex Zr, Mo and Al ions.

The limitations inherent in the use of simulated waste solutions impose, of course, great caution in the extrapolation of the results. Experiments with real waste solutions are planned for early 1976, and the Windscale reprocessing plant has been contacted for this purpose.

Radiation Damage in Glass

The object of the present work is to evaluate the behaviour of borosilicate glasses containing highly active wastes (HAW) in the very long term range. The HAW material includes a certain quantity of α-emitting nuclides some of which have an extremely long half-life. In consequence the risk associated with the waste storage system will continue to be relevant for a very long time. The total amount of radiation, and particularly of α-radiation, will increase accordingly. The hazard associated with waste storage lies mainly in the possibility that some active species may be transported into the biosphere. The typical accident usually considered is represented by a flow of water which comes in contact with the glass. In this case the quantity of radioactive material which escapes from the glass is expressed by the product of the leaching coefficient and the specific surface. It will be necessary then to study the variation, due to radiation of the leaching coefficient and to examine all the effects which could impair the physical integrity of the glass. The time to be taken into consideration is very high – estimated, in the first approximation, to be at least 100,000 years. It is necessary, then, to perform simulated tests with an acceleration coefficient of the order of $10^4 - 10^5$.

As a simulation method we chose irradiation of glasses containing uranium so that the glasses are damaged by the fission fragments.

An analysis of the simulation methods and of the possible irradiation effects was performed.

Neutron irradiation of borosilicate glasses poses some problems due to the high absorption cross-section of ^{11}B. Irradiation in a normal neutron spectrum will cause a high degree of surface damage which could give a wrong impression of the resistance of this type of glass to irradiation. To obviate this drawback two series of experiments were planned. The first, to be conducted in a normal neutron spectrum, is based on a soda-lime glass containing an appropriate amount of uranium. The use of soda-lime glass allows one to obtain preliminary results in a simple way and to perform irradiation analysis without the need of heavy shielded cells. The first series comprises the irradiation of seven capsules. Each capsule contains 5

samples of the base glass. The first four capsules contain naturaluranium while the last three were prepared using uranium enriched to 11% ^{235}U. The irradiations are performed at 50°C in the CAMEN reactor. The thermal flux is $3 \cdot 10^{13}$ n/cm^{2}s, for an irradiation time of 40 h.

In 1975 the first five capsules were irradiated; the irradiation will be completed at the end of February 1976. The post-irradiation examinations comprise: leaching coefficients, density measurements, dimensional variation, hardness measurements and microscopic examination. Preliminary results on the samples from the first four capsules show that the density tends to increase up to a maximum and then decreases. It will be interesting to follow the decreasing part of the curve at higher doses to be sure that no swelling is encountered. Dimensional variation seems to follow the same trend as the density variations. Hardness measurements show a sharp drop at the lowest dose and then tend to increase slightly. At the microscopic examination no fissures or crystal formation were detected. No results have yet been obtained for the leaching coefficient.

The second series of experiments, to be carried out on borosilicate glass, is in preparation. It will be conducted in the HFR reactor at Petten. Irradiation is scheduled to start at the end of April 1976.

A parallel study on the leaching coefficient has been initiated. Values generally available in the literature relate to short-term experiments, usually of the order of 40 days. In regard to the long-term hazard, on the contrary, very long-term leaching coefficients are needed. The few experimental values on the leaching of actinides are lower by two orders of magnitude than the leaching coefficient for Si, which can be considered a principal constituent of the glass ($\sim 10^6$ gr/cm^{2}d for Si against $\sim 10^8$ for Pu). There will therefore be an accumulation of actinides at the surface of the glass. In the long term that means that either the leaching coefficient must increase or other forms of transport, e.g. colloidal, must be present in the leaching mechanism.

We intend to study the accumulation of actinides at the surface and the Si leaching coefficient. Only very preliminary results are available up to now.

Our method of simulation does not allow of following the helium build-up inside the glass. Starting from a bibliographic study, we calculated the accumulation and diffusion of He in glasses. Some tests were done to verify the behaviour of glasses containing a quantity of He in excess of the saturation. Owing to the capacity of the glass to accept He quantities higher than the saturation values, the He build-up does not seem to constitute a problem in the long range.

Physical Studies

Assessment Studies

The questions to be answered in this context refer to

- the assessment of the magnitude of the actinides problem, if no special treatment of the actinides is applied,
- the degree of extraction of the different actinides from the radioactive waste needed in order to diminish significantly their contribution to the total long-term radiotoxic hazard of the waste,
- the feasibility of converting long-lived actinides to shorter-lived species by different types of nuclear reactors and the technical, economic and safety aspects involved in this concept.

Necessary tools for this study are an actinide evolution computer program and libraries of nuclear data for all isotopes of interest. Most of the time under review was used to prepare, set up and verify these tools. The following kinds of calculations are to be performed:

- evaluation of the build-up of actinides in different reactor type, and assuming an arbitrary degree of extraction of actinides from fuel, calculation of the decay of radioactive waste (energy release, hazard);
- evaluation of the neutron-physics feasibility of burning higher actinides in fission reactors by recycling them and the effect of recycling on the properties of the radioactive waste;
- sensitivity studies with the aim of proposing nuclear cross-section calculations and/or measurements for isotopes whose influence on the final results is remarkable, if great inaccuracies do in fact appear in the cross-sections.

Unless recycling of actinides or sensitivity studies are performed, the final results of a computation run consist of the radioactivity values for each isotope as a function of the decay time, and the hazard measures for waste and fuel, assuming that a given fraction of each isotope occurring in the irradiated fuel goes into the waste.

Recycling of actinides requires the specification of a new isotopic vector of the fuel to be fed into the reactor. Work for the development of an automatic recycling routine is under way.

In the case of sensitivity studies, the uncertainty involved in the cross-sections permits the generation of alternative group cross-sections to be used for another burn-up calculation. After having compared the results, one can decide whether it is necessary to improve the considered cross-sections.

Cross-Section Measurements

The aim of this experiment is the measurement of the ^{241} Am differential fission cross-section in the energy range of 0.5 MeV $\leqslant E_n \leqslant$ 1.3 MeV. The fission detector, a 4π gas scintillation chamber, is now being investigated at the JRC Ispra and will be used for the definite measurements with the GFK-Karlsruhe 3MeV Van de Graaff accelerator.

- Measurement programme

The purpose of the laboratory experiments is to test the performance of the 4π gas scintillation detector in order to define the operating conditions for the cross-section measurements. The first measurements were performed with a 85% A and 15% N_2 gas mixture as used by the GfK-Karlsruhe for cross-section measurements with ^{241} Pu and ^{235} U isotopes.

As fission product source a ^{252}Cf deposit (100 fissions/sec) was used on a VYNS backing of 85 ~g/cm^2 and optical shields of 45 ~g/cm^2 Au and 11 ~g/cm^2 Al. The pulse height spectrum depends very much on the A-N_2 gas flow. At very low flow--rates the valley between fission and α-events was not pronounced, and the pulse height spectrum not stable with time. Only higher flow-rates in the order of some litres/min led to pronounced valleys between α- and fission events and thus to better α-discrimination. Mass spectroscopic analysis of the exhaust gas indicated that small contents of moisture and Cl picked up inside the gas circuit from the walls caused this low and unstable scintillation efficiency at very low flow-rates.

In view of the expected high α-activity of the ^{241} Am deposits it is desired to improve still further the α-discrimination against fission signals. This amelioration can be achieved if the α-particles, having a range twice as wide as that of the fission products, dissipate a large part of their energy on the walls of the chamber and not inside the scintillation gas. In addition, the scintillation efficiency of the α-particles reaches a maximum near the end of their range whereas the fission products have their maximum at the beginning of their flight path.

The dimensions of the chamber are fixed by the diameter of the photopultipliers and with the A-N_2 gas mixture most of the α-particles dissipate their energy inside the chamber. To achieve a better α-discrimination, He gas mixtures with larger α-particle ranges were investigated in our chamber.

- Theoretical studies

The ^{241}Am fission cross-section will be measured in relation to the ^{235}U fission cross-section. For a given VDG condition we measure the fission reaction rate R of the ^{235}Am target weighted with a counting efficiency factor, in relation to the same quantity of the ^{235}U target in the collimated neutron beam. The counting efficiency factor is in the order of $0.75 \leqslant \epsilon \leqslant 0.9$ due to the high discriminator settings required for α-pile up suppression. This quantity can not be measured with ^{241} Am targets. For this reason a Monte Carlo code was developed which permits the theoretical calculation of this factor.

The code permits the calculation of the pulse height spectra of the fission products in each subchamber conditioned or not conditioned by coincidence counts. The light and heavy fission products are assumed to be distributed according to two Gaussian distributions, each defined by a mean energy and a standard deviation. These fission products are slowed down in the target, backing, optical shield and gas space before they can reach the surrounding chamber walls. For the slowing-down process in the different media of composite materials semiempirical relations were used, characterized by the composition of the target compound, the atomic weights and numbers of its constituents. In addition the mean mass, nuclear charge and mean energy of the median light and heavy fission products are required. The fission-product energy lost in the scintillator gas is transformed via a statistical resolution function into a pulse height spectrum voltage. This pulse height spectrum is compared with the measured spectrum of an ^{241} Am target, at energies above α-pile up counts. This code also serves for the technical assessment of other gas scintillation counters with different scintillation gases, targets and dimensions.

Actinides Monitoring

The aim of this programme activity is the creation of a European Central Laboratory for assessment, calibration and standardization services in the monitoring of actinides-contaminated solid waste streams. This laboratory was proposed in 1974 by the ACPM on Nuclear Waste Disposal. It was thought that services of this kind will be needed in connection with radioactive waste management and disposal problems. However, the question whether a European Central Laboratory will really be needed depends not only on our technical competence but also on the acceptance of the laboratory's role as a promotor and coordinator in the field of actinide-monitoring by the members of the European Community. In this respect some experience has been gained during collaboration with plutonium-handling facilities in Belgium, France, Italy and the UK.

At present our attention is focused on monitoring plutonium-contaminated solid wastes. Reference monitors based on the measurement of gammas and neutrons from spontaneous fission

and (α, n) reactions from Pu-decay are going to be installed. The laboratory services in this domain will be available at the end of 1976.

Measurements on large populations of waste drums from fuel fabrication and reprocessing facilities have been conducted. The measurements provide information on the distribution of the Pu content in drums. This information is useful in the designing of monitor systems.

The laboratory service is faced with some difficulties due to the considerable variety of the monitoring systems employed today in the European plutonium facilities. The variations stem from the different approaches and different views concerning monitoring objectives. This situation is aggravated by the lack of complete and organized information in the field of monitoring-system design and operation.

In order to provide a common ground for information pooling and discussions among European monitoring-system users, designers, control authorities and the central laboratory, a guide is being prepared. The guide will lead the designer through the initial steps of systems analysis and concept choice to the final stage of instrument design. It starts by setting out the various options for organizing monitoring systems, the decision--making points and the performances required of the instruments within the constraints imposed.

As a clear waste-disposal strategy in Europe has not yet been agreed upon, we suggest that the distribution of Pu-content in segregated streams should be measured. The separate distributions of non-glovebox and in-glovebox wastes segregated to "combustible" and "non-combustible" provide the information required for decision-making when a strategy is adopted. The decisions will concern treatment procedures, type of storage areas needed, monitoring ranges that should be covered, accuracies and the location of key monitoring points.

Data Evaluation

In the last few years much interest has been devoted to solving management and identification problems by systems analysis. Radioactive waste management is a large system with a great number of subsystems. The results of the analysis of large systems are the best guide for objective decision--making.

In principle real systems can be described by means of mathematical algorithms by which the interactions of the parts of the system are specified explicitly enough to make it possible to study the system's behaviour in a variety of circumstances and, in particular, to control it and to predict its future. Decision-making for the establishment of a European radioactive waste disposal system involves choosing between alternatives. In order to make his choices the decision-maker must be able to predict the performance of each alternative system. Thus systems strategy requires a mathematical model of the system.

A European radwaste disposal system which involves more than one country may be treated with the same methods. Because this system is more complex, the range of acceptable solutions is larger. It is a fact that the member states of the European Community are making efforts to coordinate their research. On the one hand this leads to a more rapid access to new data; on the other hand the individual problems of each member are recognised sooner. Disposal sites, as understood today, may not be feasible in some countries for geological reasons. This could hamper or even prohibit the future use of nuclear energy in those countries, if no other country would help to overcome their waste disposal problems for some time at any rate. A joint solution is necessary after all, because of the economic links within the Community. One can envisage an organization processing spent fuel-elements of foreign origin and simultaneously taking charge of the waste disposal. This is already done today, but under a variety of aspects. Joint research and a systematic management could continue to yield future solutions which, with joint financial effort, could solve the problems in part; one might, for instance, consider dumping actinides in the sun by means of space shuttles. European waste management also comprises questions of international law. It would be impossible to release radwaste into the rivers and lakes of other countries. Such disservices as the present mutual environmental pollution with conventional wastes must be avoided as far as radwaste is concerned. Coordinated management of the radioactive wastes within the European Community, based on system--analytical methods, seems to us a good way to master those problems in the future.

For a couple of years work has been in progress within the European Community and elsewhere for the establishment of a "European Environmental Chemicals Data and Information Network" (ECDIN). As a logical complement we propose a "European Environmental Radioisotopes Data and Information Network" (EERDIN), for which an enquiry is in preparation.

This would handle the enormous amount of data concerning radioisotopes in the environment. We believe that every specialist in this field would acknowledge the usefulness of such a tool. As to the European waste management strategy, the availability of EERDIN would reinforce and rationalise the work

Materials Science and Basic Research on Materials

V. Lungagnani

Introduction

Our main purpose is to organize phenomena oriented materials research (as related to the elucidation of natural phenomena) and generic applied materials research (as related to the demonstration of feasibility within a whole class of new devices, materials or process) as an infrastructure of technical, scientific, and instrumental competence which will respond effectively to the real materials requirements of advanced technologies.

This role of general scientific support for the current and longer-range development of advanced materials or processes is evident in the way things are managed between the Materials Objective and the purpose-oriented projects under way at the JRC. The basic principle is that staff possessing specific strong competence in the various materials fields can transfer into these projects, and come under the project management, for such periods as are needed to solve specific project problems. Thereafter, they normally return to the Materials Objective, which thus maintains major disciplinary skills in such a way that they are constantly available to other purpose-oriented projects according to demand.

Two features are particular to materials science:

a) to develop a new material (or to adapt an existing one to new uses) takes far more time than the user can normally allow for the making of new constructs. This means that we must anticipate needs and initiate R & D before the user actually applies to us for specific helps.

b) The "techniques" on which materials research is based invariably contribute to several different problem-oriented projects. When such techniques are organized in complementary form there is extra benefit to be derived from this synergy.

Thus each major area of research now constituting the "materials objective" is to some extent related to the purpose-oriented objectives of the JRC.

For orienting purposes, such relationships may be qualified as "short-range" and "longer-range" according to the following table:

"Materials" subject	Short-range relation with objective	Longer-range relation with objective
Radiation damage studies	Fusion	Safety
Surface studies	Fusion	Solar energy
Mechanical properties		Safety
Phys.prop.at high temp.	BCR-safety	Solar energy
Transport processes and structural behaviour		Protection of the environment
Effect of struct.changes and lattice imperfections		Hydrogen Solar energy
Neutron physics in coll. with the ILL Grenoble		Hydrogen

Consulted in June and October 1974, May and October 1975, the Advisory Committee for the Management of the Programmes (CCMGP) on Materials expressed its satisfaction with the quality of the work performed and with the competence shown by the staff.

More than 80 papers and original contributions to reports and conferences constituted the scientific "output" of materials objectives (see "List of Publications").

Structure of "Materials" Actions

A. In 1974 the authorized "materials" objectives involved 79 man-years (1st line) 10,5 of them for work at the Petten Establishment. The specific credits allocated to direct research costs amounted to 580.500 U.A.
The breakdown of "Materials" action into studies was as follows (see Table).

B. In 1975 a new Petten Establishment programme was approved for two years, starting from January 1975 principally devoted to high temperature materials.
In consequence of this new situation the real effort in "materials objectives" at Ispra has been reduced by 10.5 man-years, with a total specific credits allocation of 356.500 U.A. As compared with 1974 (see point A), the breakdown into studies was unchanged.

Materials science

Subject	Studies	Allocations 1974	
		(man-years)	(unity of account)
Radiation damage studies	Void formation studies to determine the cavities formed in materials during irradiation; diffusion, radiation damage and defects in fcc materials	2.4	33,000
Surface studies	Particle surface interaction studies; effects of ions on materials; desorption studies; compatibility of fusion-reactor first-wall materials with blanket materials	14.0	62,500
Mechanical behaviour	Composite materials obtained by gradual increase "in situ" starting from eutectic alloys; phase-dispersed materials studies- cavitation in steels and other structural materials; fracture studies; correlation between S.W.E. and structure during tensile deformation of composite materials. (at Ispra) Single crystals of vanadium growth and doping; irradiation and mechanical post-irradiation testing of vanadium and its alloys; effect of helium bubbles and voids on ductility (at Petten)	30.7	187,500
Physical properties at high temperature	Gas-controlled vapour chambers; wetting studies at high vapour pressure; vapour pressure measurements between 2000°C and 3000°C	3.7	19,000
	TOTAL	50.8	302,000

Basic research on materials

Subject	Studies	Allocations 1974	
		(man-years)	(unity of account)
Transport processes and structural behaviour in metals, polymers and related materials	Quantum effects in nuclear magnetic relaxation; diffusion of hydrogen in transition metals; nuclear relaxation and diffusion behaviour of liquid crystals; electron spin resonance studies of free radicals during fast electron irradiation; determination of hydrogen mobility, activation energies and physical and chemical adsorption heats	12.5	185,000
Effect of structural changes and lattice imperfection on the properties of materials	Diffusion, radiation damage and defects in bcc materials; optical methods for the study of surface, lattice defects and phase transitions; application of x-ray and γ-ray scattering to the study of lattice defects and phase transformations in solids. Computer experiments on unharmonic lattices	9.4	44,500
Neutron physics (in collaboration with ILL of Grenoble)	Neutron optics studies; fission fragment interaction with matter; study of neutron procession experiments; neutron scattering experiments on single crystals of Pd and Ce doped with H, D and T; study of the hydrogen diffusion mechanism in RCo_5 and RNi_5 compounds (R =La,Pr)	8.7	49,000
	TOTAL	30.6	278,500

Progress and Highlights

A) Materials Science

The materials programme has now been running for three years, and it is possible to assess the value of the topics chosen in this field. In general, all the activities are making constant progress. The difficulties that a certain number of new activities encountered in the first year have been overcome. In all cases the experimental set-up has been completed and work has reached the measurements phase. Some activities suffered, however, from the breakdown of the 1 MeV Van de Graaff generator.

The work in radiation damage yielded a further elaborate insight into the image-forming of small holes and bubbles by the Electron microscope and showed us what may be the best way to visualize small cavities.

Diffusion of point defects and the influence of their migration on the structure of alloys has become a strong point of the programme. Competent staff and good equipment are yielding a constant output of results in this field. A number of problems have been treated, including self-diffusion in nickel, the ordering and structure of gold-silver alloys, the precipitation of iron in copper and the behaviour of point defects in copper gold alloys. In the field of surface phenomena, the first results from the blistering studies were obtained. The apparatus has proved to work well and further results will become available as soon as the difficulties with the Van de Graaff generator are overcome.

The measurements on adsorption and desorption of gases on the surface transition metals are proceeding with the apparatus developed during the first year of the programme. The results obtained in 1974 concern the system Mo-N_2 in the temperature range 200° K to 800° K.

The ion implantation laboratory investigated

arsenic ions in silicon and has started, in collaboration with other activities in the materials programme, the study of oxide grown on silicon carbide. In 1974 a new study on the compatibility of liquid lithium with transition metals was started. This work is still in the stage of preparation of the experimental equipment.

A major part of the materials programme is devoted to the study of mechanical properties of metals. The different mechanisms which may play a rôle in the plastic behaviour are investigated. The observations are partly used for the preparation of new materials. The work concerned with the preparation of metallic composites from eutectics furnished a fairly complete picture on the growth mechanisms of fibre-reinforced Al-Ca alloys, obtained by unidirectional solidification. The field is constantly being extended and materials of extreme properties, for example superplastic alloys can now be prepared. Hardening by a stable dispersion is the objective of a parallel study. This study is concerned with nickel-base alloys, and the method employed allows a wide variation of parameters.

The knowledge on the mechanisms which limit the mechanical strength are necessary for a successful application of known materials and for the development of new alloys. Besides the classical methods of investigation such as tensile tests, creep tests and the study of defect structures in the electron microscope, a special effort is being made in three new directions and has already given remarkable results.

These are:

i) the measurement of the density of deformed materials, a method which makes it possible to follow the formation and growth of microfractures,
ii) acoustic stress wave emission, where our work on the identification of stress wave sources has been very successful, and
iii) dynamic experiments in the scanning electron microscope.

Research and technological development were continued in the field of heat pipes. There are quite a number of problems involved in their performances which give rise to a number of possibilities of studying materials and their interaction with one another in very definite conditions. Wetting studies of liquid sodium on stainless steel, tungsten niobium, tantalum and molybdenum in the temperature range between 540° and 700°C were performed in a specially adapted heat pipe.

Part of the programme was executed at the Petten JRC, where the well-established competence in the field of preparation of high-purity vanadium was used to start systematic studies of the influence of impurities on the mechanical properties of single crystals, on the recrystallisation of deformed vanadium and on the formation of voids and gas bubbles in the irradiated metal.

B) Basic Research on Materials

The reorientation of basic research in the field of Physics of Condensed Matter was started in 1973 and completed during the year 1974, in order to comply with the multi annual Materials Science programme approved by the Council of Ministers.

The existing installations for magnetic resonance, for X-ray and Mössbauer scattering, for optical scattering and spectroscopy, and for electrical resistivity and sputtering techniques were improved and modified to fulfil the needs of the approved programme. Some of the neutron physics activities that were previously going on at the Ispra-I reactor were moved to the Institute Max von Laue – Paul Langevin of Grenoble where the JRC team seconded to the Institute continued with the work in progress since a number of years.

In the field of Structural Changes and Lattice Imperfections of Solids a number of research projects were initiated or completed. More specifically, concerning phase transformations:

1) The formation of the ω-phase in Zr-20% Nb alloys was investigated by using diffuse X-ray and Mössbauer scattering techniques. Intensity measurements of various diffuse peaks associated with the presence of the ω-phase were done at temperatures between liquid nitrogen and room temperatures. The results indicate that the mean positions of the atoms inside the unit cell of the ω-phase vary reversibly with temperature.
2) A neutron scattering experiment was performed at the ILL Grenoble on deuterated potassium dihydrogen phosphate around the critical temperature of the ferroelectric transition. A double-crystal spectrometer, that was designed and built in Ispra, was used for this experiment. It was found that phase mixing occurs at the critical temperature, that is, the para- and ferroelectric phases, with slightly different lattice parameters, coexist in a narrow temperature interval around the critical temperature.
3) As to optical scattering, our activity was concentrated on assembling and testing an apparatus for the study of Brillouin scattering. The electronic hardware was set up and we began to calibrate the apparatus by means of experiments on coherent and incoherent light scattering for lithium niobate.
4) Theoretical work in the field of non-linear classical mechanics continued mainly along two lines. First, we further refined and extended the computer program for the evaluation of the motion of a one-dimensional chain of particles iteracting via a Leonard-Jones type of potential. Secondly, the transition from a regime of order-

ed motion at low energies to a regime of stochastic motion at higher energies was investigated for systems containing up to five hundred particles.

We did extensive work using an X-ray scattering technique to investigate the diffuse peaks associated with the presence of short-range order in gold 50% silver alloys. Measurements were done in "as-grown" and fast-electron-irradiated crystals. The results showed that the effects of the annealing and irradiation treatments on the amount of short-range order were small. These results will be compared with those obtained by means of precise electrical resistivity techniques. The preparation of the experimental equipment needed to work with body-centred cubic materials was continued. A titanium sublimation pump and a molecular pump were purchased in order to perform annealing treatment in the ultra-high vacuum combinations required by most of the metallic materials with b.c.c. and hexagonal structures. We started self-diffusion studies on zirconium crystals, using a refined sputtering technique, and the diffusion of hydrogen in vanadium hydride ($VH_{0.3}$) was investigated by means of nuclear magnetic resonance. In this last case activation energies for diffusion were measured at low and high temperatures.

Other nuclear magnetic resonance work concerned the investigation of diffusion phenomena and of Zeeman and dipolar relaxation time in polymorphic liquid crystals that were synthesized in the laboratory, and the continuation of studies on thermally induced polarization. Lastly, one NMR spectrometer was automated by a connection on-line with a PDP 11 computer and the software was developed for the automation of relaxation times measurements. Electron spin resonance work was mainly devoted to studies of frozen aqueous solutions of nucleic acid bases, of oxygen-saturated ice and to some preliminary studies of DNA samples. Some theoretical work on nucleic acid bases was also started.

The neutron optics team, working at the ILL Grenoble, completed the design of a high-resolution neutron diffractometer which is now being built. Investigation of special types of neutron monochromators was continued, particularly in connection with composite focusing systems made of Cu-Ge crystals having a gradient in the lattice parameter. Some studies were also devoted to neutron topography and neutron scattering of liquid crystals. Finally, the group working on fission-fragment experiments continued the preparation of the multisection ionization chamber and of the data collection system that will be used with the ILL Lohengrin spectrometer at Grenoble.

Non-electrical Application of Nuclear Energy Hydrogen Production from Water

G. Beghi

Introduction

Research on Hydrogen Production from Water was motivated by the possibility of extending in the long term the application of nuclear energy to non-electric uses; as the European Community is highly dependent upon external sources of primary energy, it is useful, from the standpoint of a guaranteed supply, to further extend the use of nuclear energy.

Hydrogen is an excellent candidate as "energy carrier" to transfer nuclear heat from the power station to all users; moreover, it has essentially non-polluting combustion characteristics. For these reasons, hydrogen could have a very large influence on the future energy market; its consumption for conventional uses is already very high and its potential as a fuel is recognised as being one order of magnitude higher.

Whatever may be the future of a hydrogen fuel economy (by about the year 2000 and later), hydrogen will become increasingly important as a chemical feedstock since it is the basic raw material (and major cost) for instance for fertilizers, for several chemical compounds including methanol (considered as a possible substitute for gasoline or other liquid fuels), and for oil desulphurization; in the near future it will also be used in large quantities for coal hydro-gasification and in the steel-making industry.

Currently, most hydrogen is produced from natural gas and oil. As these supplies diminish, alternative methods of large-scale production will be required and serious efforts are needed to develop new technologies for hydrogen production from non-fossil raw materials.

A possible new method for hydrogen production using water and nuclear (or perhaps solar) heat is the thermochemical decomposition of water, i.e. a chemical process based on a closed cycle of chemical reactions operating at temperatures compatible with nuclear reactor technology.

JRC Activities

The specific objective of the Ispra research is to evaluate the potential of this thermochemical decomposition of water, from the standpoint of the technical feasibility of large industrial plants and the economics as compared with the rival process, the electrolysis of water. Our work is still in its initial research phase, the aim of which is:

- to explore the possibilities of identifying useful chemical cycles
- to evaluate their potential interest and to define their characteristics and feasibility with experimental tests.

The purpose of this research phase is to prepare information as a basis for the selection of promising cycles.

The main lines of the programme are the following:

- *chemical studies:* these include thermodynamic calculations, identification of new possible cycles, experimental verifications;
- *kinetic studies :* all the problems related to the study of the influence of different parameters and to the preparation of bench-scale testing of chemical reactions in steady-state conditions;
- *material studies :* corrosion tests in various corrosive media, to screen possible materials for the more promising processes;
- *general evaluations* for the preliminary calculations of process flow-schemes, thermal optimization, chemical engineering problems, etc.

A summary of the budget (excluding personnel costs) and manpower allocated under these headings is given in the following table:

Action	Budget (u.a.)		Manpower (Man/years)	
	1974	1975	1974	1975
- Chemical, kinetic studies, materials, general evaluations,	180,000	165,000	34	35
- Contracts	50,000	200,000	-	-
TOTAL	230,000	365,000	34	35

An outstanding event was the formation, at the beginning of 1974, of an Advisory Committee for the Management of the Hydrogen Programme, following the decision of the Council of Ministers

(resolution R/2735 F/73-ATO 161 approved November 19, 1973). This Committee, with about twenty delegates, met three times in 1974 and twice in 1975; two opinions were formulated summarizing the views of the members on the current Ispra Hydrogen Programme. These documents and the individual views expressed in the Committee are of considerable help in the management and orientation of the programme.

The Hydrogen Programme team, together with the Directorate-General for Research and Science, Brussels, organized a scientific seminar on Thermochemical Decomposition of Water. This special two-day meeting was held in Paris on 28-29 April, 1975 and was attended by twenty experts from European Community countries, the USA and Japan: it gave these scientists the opportunity of a vigorous discussion and exchange of ideas and views on four main items: 1) criteria for definition and evaluation of thermochemical cycles, 2) state of the art in the world, 3) critical points in the development of processes, 4) orientation and guidelines for future research.

Links with External Organizations

An agreement for cooperation, signed during 1973, is operating between the Commission of the EC, the Kernforschungsanlage Jülich GmbH and the Rheinische-Westfälische Technische Hochschule in Aachen. During 1975, the French Atomic Energy Commission's Centre d'Etudes Nucléaires, Saclay, joined the agreement.

The cooperation consists in a mutual exchange of information and the coordination of some common activities; technical meetings are periodically held.

During 1975, the International Energy Agency set up a Sub-Group on Energy R&D, which recommended the implementation of a cooperative R&D programme on Hydrogen production from water. The Commission of the EC, through the Joint Research Centre, Ispra, was designated to act as leading organization for the cooperative programme in the Hydrogen area.

Development of the Research : A Summary

During the years 1974 and 1975 the study continued with the identification of new cycles and the experimental testing of critical chemical reactions. The scheme of activities necessary for the development of a new thermochemical process for water decomposition comprises a number of steps, as shown in Fig. 1; this scheme has to be applied to any cycle, being stopped if negative results are obtained in one or another of the various aspects which have to be considered in the evaluation of a process.

The following paragraphs summarize the principal results of our exploratory work; in the light of the data obtained with theoretical and experimental evaluations, some main conclusions were reached.

Studies on Chemical Reactions

The chemical reactions studied in this period are grouped in different "families"; the main families examined are the following:

Cycles of the Mark 1 family

The first cycle defined at Ispra was the Mark 1, a cycle patented in 1969 and using mercury, calcium and bromine as chemical elements. The tests made added to our knowledge of this cycle and possible variations. During 1974 measurements were made on the hydrolysis reaction of $CaBr_2$ at high pressure and on the reaction of concentrated $HgBr_2$ solutions with calcium hydroxide. Good results were obtained but owing to possible pollution problems the work on cycles using mercury was stopped, in keeping with the recommendation included in the opinion formulated by the Advisory Committee for the Management of the Programme.

Possible variants of the Mark 1 cycle using other elements instead of mercury were examined but the results were not encouraging.

Iron-chlorine family

Water-splitting cycles using iron and chlorine are among those more extensively studied during the last two years in laboratories throughout the world. The iron-chlorine cycles proposed by various authors have some common reactions which, in different combinations, lead to various processes.

Hydrogen is usually obtained during the hydrolysis of iron-dichloride, in some cases through its previous reduction to iron. The usual reaction is:

$$3FeCl_2 + 4H_2O = Fe_3O_4 + 6HCl + H_2$$

Chlorine is always obtained by $FeCl_3$ decomposition:

$$2FeCl_3 = 2FeCl_2 + Cl_2$$

Oxygen is obtained by the action of chlorine on iron oxides or on water, in this latter case sometimes through magnesium chloride or oxichloride. At Ispra we also studied the possibility of obtaining oxygen from a combined action of chlorine and hydrocloric acid on iron oxide.

All the reactions were studied with a view to collecting data for the design of a plant; information on equilibrium measurements has to be supplemented with results from tests in conditions

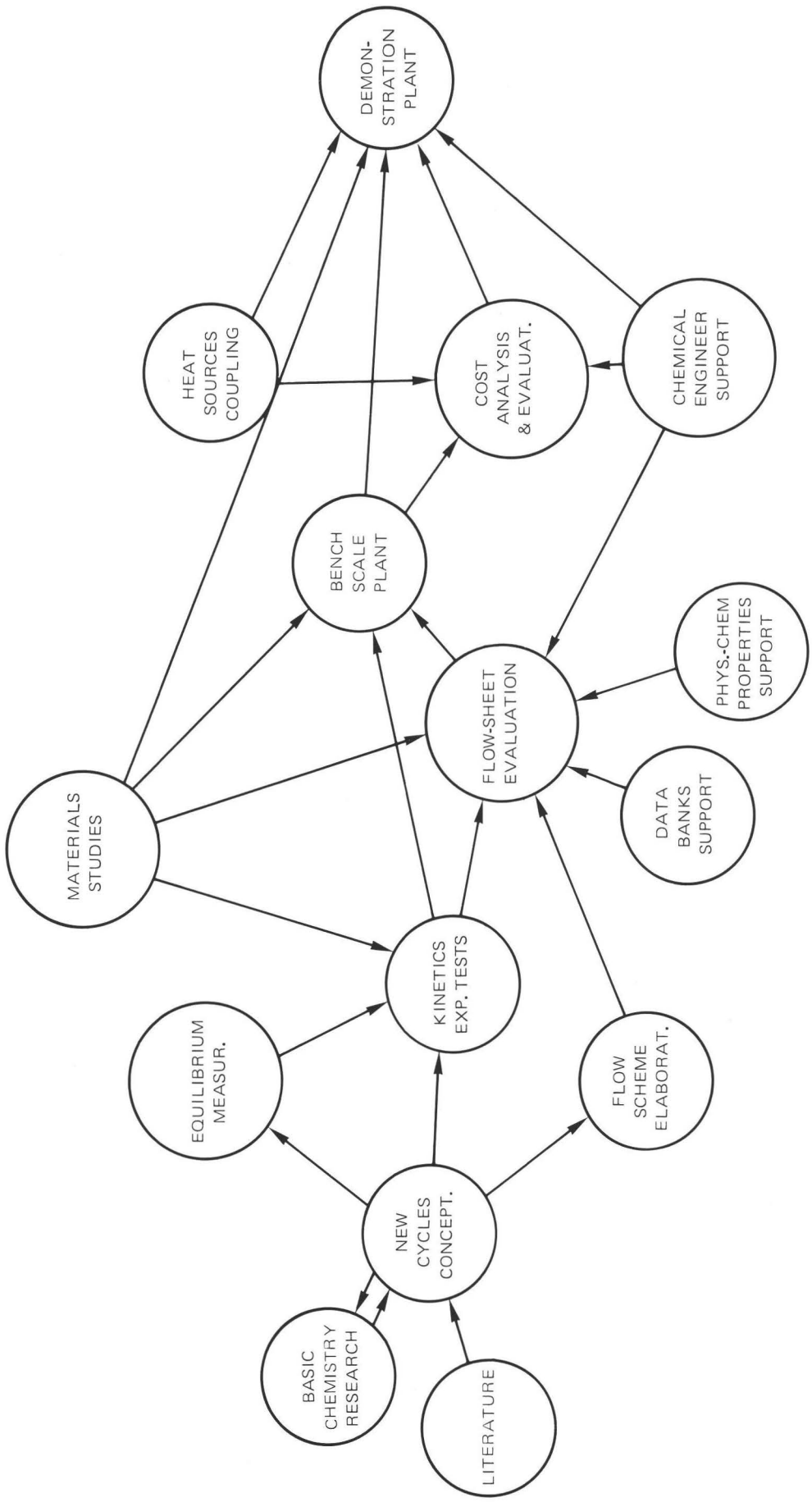


Fig. 1 Work Scheme for the Study of a Thermochemical Process for Water Decomposition

approaching those which are foreseen in a continuous operating plant.

The hydrolysis of $FeCl_2$ has been thoroughly tested; the study was also extended to the selection of possible support materials for $FeCl_2$, with a systematic analysis of several candidate materials. With or without support the hydrolysis reaction was found feasible from a kinetic point of view. The conditions finally adopted for this reaction are the following:

temperature 650°C
pressure 1 atm
water conversion 21%.

We examined and tested the decomposition of $FeCl_3$ to $FeCl_2$. The conditions finally adopted were the following: temperature : 280°C for the evaporator and 200°C for the $FeCl_3$ condenser; pressure : 1 atm; carrier gas, carbon tetrachloride at a partial pressure of 0.12 atm at the evaporator temperature. In these conditions a 1 to 7 ratio between chlorine and the dimer Fe_2Cl_6 is expected for the vapour phase in the hot zone.

Chlorination of magnetite was extensively tested with mixtures of hydrochloric acid and chlorine in different conditions, in the temperature range from 80°C to 200°C.

The conclusions are that chlorine does not react to any large extent, and only a limited amount of the expected oxygen is formed. Oxygen can be formed in due amount if the working temperature is raised to about 730°C, but at the expense of an unacceptably low conversion of the hydrochloric acid. These results induced us to change the conditions for the chlorination and oxygen formation step; it was decided to use less chlorine (one-third of the previous amount) for the reaction on magnetite, the remaining chlorine being used to produce oxygen by the reverse Deacon reaction. The chlorination of magnetite is an exothermic reaction; in order to improve heat recuperation the reaction temperature has to be as high as possible; the first part of the chlorination with chlorine alone:

$$3Fe_3O_4 + 3/2\ Cl_2 \longrightarrow FeCl_3 + 4Fe_2O_3$$

can be done at 700°C with a very high conversion rate (96%), the subsequent chlorination of Fe_2O_3 with HCl has to be done at a far lower temperature (160°C) in order to maintain a high HCl conversion rate (79 %).

In a subsequent evolution, the reaction of magnetite with gaseous HCl was studied; experimental tests were made in the temperature range between 130 and 400°C. The reaction is the following:

$$Fe_3O_4 + 8HCl = FeCl_2 + 2FeCl_3 + 4H_2O$$

At temperatures lower than 160°C only $FeCl_2$ and $FeCl_3$ (and water) are formed, over 160°C FeOCl begin to be found, and above 300°C $FeCl_2$ and Fe_2O_3 are the more abundant products. The final conditions adopted for this reaction are the following: temperature 160°C; pressure 3.5 atm, conversion rate of HCl 79%.

On the basis of the above-mentioned results, several sequencies of reactions were defined, and examined with the computer program OPTIMO for the evaluation of processes; the scheme which corresponds to a minimum amount of circulating materials is the following (cycle Mark 15) :

$$3FeCl_2 + 4H_2O \longrightarrow Fe_3O_4 + 6HCl + H_2$$

$$Fe_3O_4 + 8HCl \longrightarrow FeCl_2 + 2FeCl_3 + 4H_2O$$

$$2FeCl_3 \longrightarrow 2FeCl_2 + Cl$$

$$Cl_2 + H_2O \longrightarrow 2HCl + 1/2\ O_2$$

For the last reaction of this sequence, the reverse Deacon reaction, the following conditions were adopted: temperature 600°C, pressure 2 atm, Cl_2 and H_2O conversion rate 42%.

Sulphur cycles

Another family of cycles is that based mainly on SO_3 decomposition, using sulphur as one chemical element, with others that may be varied from one cycle to another. This family includes processes based on chemical reactions only or including an electrolytic step. The common reaction is the following:

$$SO_3 = SO_2 + 1/2\ O_2$$

the SO_3 coming from the decomposition of H_2SO_4 or from a metal sulphate. The remaining reactions used for closing the various sulphur cycles studied at present in the JRC are the following:

For Mark 11

$$SO_2 + 2H_2O = H_2SO_4 + H_2 \quad \text{(electrolytic reaction)}$$

For Mark 12

$$SO_2 + I_2 + 4NH_3 + 2H_2O = (NH_4)_2SO_4 + 2NH_4I$$

$$(NH_4)_2SO_4 + ZnO = ZnSO_4 + 2NH_3 + H_2O$$

$$2NH_4I = 2NH_3 + I_2 + H_2$$

For Mark 13

$$SO_2 + Br_2 + 2H_2O = H_2SO_4 + 2HBr$$

$$2HBr = Br_2 + H_2 \quad \text{(electrolytic reaction)}$$

For Mark 16, a new cycle under study

$$SO_2 + I_2 + 2H_2O = H_2SO_4 + 2HI$$

$$2HI = H_2 + I_2 \quad \text{(in liquid } SO_2 \text{ as solvent)}$$

Progress has been made in the study of SO_3 decomposition in the temperature range 750-850°C. The results from a research contract with Péchiney Ugine Kuhman show that the kinetics of SO_3 decomposition with a catalyst is quite fast and that O_2 and SO_2 concentrations near (80÷90%) the equilibrium value can be ob-

tained in a short time. It has been evaluated that the volume of the chemical reactor for SO_3 decomposition is about half the volume of an equivalent reactor for SO_3 synthesis.

Another reaction which has been studied is the decomposition of ammonium iodide, for the Mark 12 cycle. Various catalysts were tested; the aim is to improve HI decomposition without affecting the NH_3 decomposition. Good results were obtained by the use of Pt alone or supported. When using γ-alumina it appears that as well as the catalytic effects there is also an absorption effect; it seems possible to conceive a decomposition reactor which would retain the iodine formed, this iodine being afterwards recovered by desorption at higher temperature.

The study of the electrolytic reaction of the Mark 13 cycle is in progress. The experiments deal with many parameters. The geometry of the cell has been studied, with and without diaphragm, and with static or moving electrolyte. Tests have been made with different electrode materials, various kinds of graphite, noble metals and alloys. The influence of temperature, the HBr concentration, the electrolyte composition (presence of H_2SO_4) have also been studied. The results show that working at 100°C at 1 V the maximum current density achieved with graphite electrodes is about 200 mA/cm^2, a value usually adopted for industrial water electrolysis. Work is in progress to improve the cell performances yet further. With activated noble metal electrodes the same current density can be obtained at only 0.7 volts.

The study of the reaction between SO_2 and I_2, and water, is oriented to solve the problem of the separation of sulphuric and hydroiodic acids: without this separation, this reaction cannot be used in a thermochemical cycle. The difficulty has been circumvented by using a particular solvent; under this condition two phases are obtained, one mainly constituted by H_2SO_4 (about 50% by weight) and the other in which hydroiodic acid and unreacted iodine are dissolved.

Material Studies

In the present research phase, studies on materials are limited to a screening of commercial metallic and ceramic materials and to preliminary selection of possible construction materials for the important part of the processes. This study, in the case of the Mark-1 cycle, was completed in nearly all the main items. Corrosion resistance in hydrobromic acid and other environments was measured for metallic and ceramic materials. The exposure times for all the tests were extended to 5000 hours (about 7 months) to cover a reasonable fraction of the possible life of the equipment involved, because the corroding agents or their concentrations have largely unknown effects and it is difficult often even to postulate the probable mechanism of their action. Under these conditions an empiric approach in unavoidable, at least during the screening of materials, and long exposure times become necessary to allow reasonable extrapolations of corrosion rates in order to estimate the possible lifetime of the components involved. The corrosion data collected for Mark 1 show that suitable materials have been found for all the most critical conditions of the cycle. The corresponding corrosion rates are, in general, quite acceptable.

A summary of the possible materials for the different parts of the plant was prepared.

Concerning the iron-chlorine family, preliminary corrosion tests were made in hydrochloric acid, the main corrosive agent in these cycles. The temperatures were considered in the various ranges, 200°C, 400°C, 600°C, 700°C, 800°C; dynamic tests are being carried out in quartz loops. The commercial materials tested are ceramic and metallic. For the low temperature range various materials can be considered as practicable. For the high temperature range promising results have been obtained with ceramic materials, such as alumina, Mullite, Sillimanite, zirconia and others, and with some Ni-alloys, such as Hastelloy C, Inconel 625, IN 691, 6X.

Some orienting tests have also been started on corrosion in hydroiodic acid at 400-600°C and in some other environments, for various cycles taken into consideration.

General Evaluations

In the phase of exploratory studies our objective is to identify and select possible thermochemical cycles, in order to reduce to a minimum the number of cycles to be studied and developed with expensive experimental tests. This is done by:

- establishing a comprehensive set of criteria to be used for comparing thermochemical cycles with each other and with electrolysis. Several criteria have to be defined in evaluating the promising characteristics of the processes, ranging from thermal efficiency to kinetics, separation of products, transport of heat and of solid materials, chemical losses, etc.
- establishing methods for an early evaluation of the processes, with approximative calculations made in various successive steps. The preliminary thermodynamic evaluations must be integrated with technological and economic parameters, in order to clarify the final view of industrial feasibility. The characteristics which are related to the chemical plant/nuclear reactor complex have to be taken into particular consideration.

Studies related to these general evaluations are mainly the following:

- implementation and use of the computer program OPTIMO. In consideration of the size of the problem, this program prepared for conversational use, was conceived as a modular program. It consists of a central manager program and many subprograms. Each subprogram solves a particular engineering problem in the flow-sheeting field: mass balance, energy balance, heat recovery optimization, nuclear reactor coupling, efficiency evaluation, general evaluations and other subprograms for input and output data control, data library, etc. Each subprogram can call any number of routines to solve particular mathematical problems. The modular structure makes it easier to introduce new subprograms or routines without modification of the work already done. This is the case when new evaluations are required.

During this last period the subprogram for heat recovery optimization was modified in order to introduce different values of minimum ΔT in different heat exchangers, corresponding to various foreseen cases: Vap-Vap, Vap-Liq, Vap-Gas, Liq-Liq, Liq-Gas, Gas-Gas. Solids are considered by using an intermediate solid-gas heat exchanger to increase or decrease the required or available temperature. Like all the input data, these parameters (values of minimum ΔT) can easily be changed.

The OPTIMO program was applied to the evaluation and comparison of all the cycles taken into consideration and sufficiently known. The code was used to give detailed information, not only mass and heat balances, thermal optimization and process nuclear reactor coupling, but also for sensitivity analysis. This sensitivity analysis procedure has been used to determine the influence of variations in some of the more important input data, and provided useful information on the weight of each parameter and a possible motivation to increase or decrease the corresponding experimental work. The input parameters were, for instance, reaction temperature, chemicals conversion, concentration, etc.

- Techno-economic evaluations. In the present exploratory phase of the research detailed and sufficiently accurate estimates for the economic viability of this new method are not possible, due to the incertitude on the cycles and on the flow sheets. However, techno-economic evaluations, although necessarily approximate and based on minimum information, are useful in this early stage of the development of the study. For this reason, a study was started, in connection with an industrial company, taking some chemical cycles as a reference and making several assumptions for the unknown data. The target is to have approximate evaluations on some specific cycles, in order to make relative comparisons and put in evidence possible specific characteristics and critical points. The study is done with criteria used in chemical industry and has to be considered with all the above mentioned limitations; the work is in progress and from the first results a preliminary observation can be made: the confirmed, high importance of the investment costs in these processes (not less than 50% of the production cost). This can be useful in orienting the research for new cycles.

- Cost estimates. In parallel to the evaluations of the investment costs for the industrial processes, based on calculations of detailed flow-sheets and considering the chemical engineering aspects in the technological realizations, as in the above-mentioned techno-economic studies, cost estimates are made with approximate methods. Several of these methods, used by the chemical and petrochemical industry, were tested and two of them were retained as more closely corresponding to the specific case:
  - the Stallworthy method
  - the "functional unit" method.

These methods are based on mathematical formulas using correlation constants, number of main units, material factor, pressure factor, temperature factor, complexity factor, plant capacity, ratio between average stream and plant capacity, etc. The investment costs for the plants of different processes are calculated and are used for evaluating the hydrogen production cost for each process. Even with the approximation linked to these simplified calculations, useful comparisons can be made which show up the processes that would entail higher plant costs. The hydrogen costs in the examples taken into consideration vary in the range of 5.8 to 7.4 $/MBTU, with a heat cost of 1.5 $/MBTU.

As a reference, the hydrogen production cost for electrolytic processes was calculated; with conventional electrolysis the cost is 10.6 $/MBTU. Taking a figure of 80% of this cost as corresponding to the possible improvements in advanced electrolysis, the cost is reduced to 8.5 $/MBTU. Parameteric analyses were made as a function of the energy cost and it was concluded that thermochemical processes are competitive with electrolysis.

Other evaluations were made, calculating for the thermochemical plants the maximum investment costs that are still competitive with electrolysis, and doing parametric analyses as a function of thermal efficiency, energy cost, etc. Results confirm that the maximum investment cost that allows of being competitive is considerably higher than the investment costs calculated with the above-mentioned methods.

Reactor Safety Programme

E. Burck, R. Klersy *

* *Edited in collaboration with those responsible for the different activities.*

The primary object of the JRC Nuclear Safety Programme is experimental and theoretical investigation of reactor safety problems for Light Water Reactors (LWR) and Liquid Fast Breeder Reactors (LMFBR). The increasing activity of the JRC in this field has been stimulated by the different European and International Committees involved in reactor safety research, where constructors, licensing authorities, national laboratories and utilities are represented.

The Advisory Committee for the Management of the Safety Programme, which meets three times a year, discussed the progress and the future course of the different activities and advised on the JRC proposal for the next multiannual safety programme. Detailed technical discussion on the JRC activities in the safety field also takes place in five "Ad Hoc Specialist Working Groups" set up by the ACPM-Safetv:

- Blowdown, Part B
- LMFBR Subassembly Thermohydraulics
- Reliability
- Core Melt Down and Fuel-Coolant Interaction
- Structural Failure Prevention.

The extremely close connection between the JRC safety programme and the different national programmes and needs is also expressed in about 20 collaboration contracts, the countries contributing a total of about 5 million u.a. towards the JRC activities. In the present multiannual programme the work was regrouped into five main areas, for which the Community investments and manpower were as follows:

Area of Activity	Investments (u.a.)		Manpower (man/years)	
	1974	1975	1974	1975
Engineering research	197,500	155,000	25	25
Coolant thermohydraulics	375,500	300,000	63	68
Early failure detection	63,000	56,000	10	11
Reliability	11,200	11,000	9	7
Theoretical accident analysis	–	–	8	11
TOTAL	647,200	522,00	115	122

The main achievements of this programme in 1974 and 1975 are documented in more than 80 publications and described in detail in the Annual Progress Reports for 1974 and 1975. The present chapter is only a very short version of these annual progress reports, summarizing the running activities and the main achievements.

Engineering Research Associated with Catastrophic Accidents and their Prevention

Structure Loading and Response

The progress on the above activity will be summarized under the following main headings:

- Study of consequences of a DBA in the PEC and SNR reactors
- First results of the Ispra code development and validation programme
- Development and validation of finite-element structural and hydrodynamic codes
- Work done to specific order.

The **study of consequences of mechanical energy releases** in the PEC and SNR reactors was continued in close collaboration with CNEN and BN respectively. A combined experimental and theoretical approach is used to predict the consequences of a DBA (Design Basis Accident). For both reactors 1:6 scale models were designed and constructed for a final demonstration test. For these experiments a large amount of preparatory work was necessary concerning choice, mounting and calibration of the instrumentation and the calibration of explosive charges. Tests were also performed in an old vessel (about 1:6 scale) for SNR, and in 1:10 scale mock-ups of PEC in which the behaviour of important safety structures like shield tanks, perforated plates and plug hold-down devices were investigated.Some of these experiments have been analysed with the REXCO H release 2 code; for this purpose the code was modified to make it capable of dealing with pressure release waves, large fluid flow and fluid plug impact.

Ispra started the **containment-code development and validation programme,** collecting 2-D coupled hydrodynamic and structural codes availa-

ble in the Community. These codes – ASRARTE (2-D Lagrangian) developed by UKAEA, ARES (2-D Lagrangian) developed by Interatom and SURBOUM (2-D Eulerian) developed jointly by BN and UKAEA – are now working on the Ispra IBM 360/75 computer and are available to all Community countries.
In agreement with the views of leading experts in the field, theoretical work was started on the following subjects:

- Preshot and validation calculations (completed for 2 experiments)
- Introduction of compressible hydrodynamics in SURBOUM
- Study of a new equation of state for water.

After extensive discussion of the validation test series a set of 22 geometrical configurations was established. Three of these tests were performed, using a new bunker and a new data acquisition system.

The above-mentioned **finite-difference codes** are able to calculate the deformation of axisymmetric structures with thin shell theory. 2-D and 3-D finite element codes (EURDYN 1-2-3) for non-linear transient structural response were developed at Ispra for the study of more complicated structures such as core internals and stress concentration points. The results of these codes were compared with those of other codes (like NONSAP). Initial validation experiments were performed and showed good agreement between calculated and measured results. In 1975 the concept of a more general code development and validation programme was defined; its aims include the development of a coupled finite-element hydrodynamic and structural code and the performance of validation experiments.

A not inconsiderable part of the available resources were used to solve **specific questions at the request** of various organizations. Such work included:

- Contribution to the performance of an experimental programme on hypothetical pressure-tube rupture in the CIRENE reactor. Use of the REXCO code to perform some exploratory calculations.
- Analysis of a DBA in a gas breeder reactor, Work performed under contract with GBRA Brussels.
- Calculations performed for C.E.A. Cadarache
- Implementation of the codes EURDYN 1-2-3 at Risø for Danish Atomic Energy Commission.

Stress/Strain/Strain-Rate Measurements for Steels

The experiments to determine the stress-strain diagrams of core and vessel materials under dynamic conditions are being continued in collaboration with the CNEN, GfK and UKAEA. The experiments in the strain-rate of $\epsilon = 10^{-2} - 10^{3}$ sec^{-1} and the temperature ranges of 20, 350 and 500°C have been completed for the following materials: AISI 316 L, DIN 4306, DIN 4981, St 35 and several other steels.

A pneumatic device for bi-axial tests has been developed and is nearly ready for operation. This experimental device allows tests in two perpendicular directions by tension and compression for strain rates of $\epsilon = 10^{0} - 10^{2}$ sec^{-1}.

A shock-tube for very high strain-rate conditions ($\epsilon > 10^{3}$ sec^{-1}) and for missile collision studies has been developed and is now ready for operation. Preliminary wave propagation tests on specimens of length comparable to that of the real structure are under way and may contribute to the study of constitutive equations of materials in dynamics.

Thermophysical Properties of Core Melts

For the analysis of hypothetical core melt-down accidents it is necessary to know certain physical properties of the core melt, the most important being the viscosity and the surface tension. The JRC work in this field, sponsored by a collaboration contract with the BMFT has centred on measurement of the viscosity and surface tension of LWR molten core mixes, known as "corium". This entailed developing crucibles compatible with the "corium" and its components, and fabricating a corium that guarantees a homogeneous melt. After calibration of the viscosity measuring apparatus, measurements were performed for the three separate components of corium, i.e. UO_2, Zircaloy and stainless steel. Preliminary measurements of the viscosity of corium E have been carried out and must be evaluated. The surface tension measurement facility has been tested and improved and the first measurements have been carried out up to 2000°C.

*Fracture Control in Fast Reactor Structures**

Work during 1974-75 continued largely along the lines laid down in 1972-73, and was devoted to basic studies on the growth and instability of cracks in austenitic stainless steel (AISI 304) taking into account the effects of a typical LMFBR environment.

The study of the toughness degradation by thermal aging of AISI 304 steel evaluated by COD and J- integral measurements has been completed and showed that in spite of a marked effect on the measured parameters, temperature aging did not

* *See in the selected topics the paper "A fracture mechanics evaluation of toughness degradation due to the thermal aging" of austenitic stainless steel by B. Henry.*

dangerously modify the crack tolerating capacity of LMFBR structures. A similar study concerning the effect of irradiation has been launched and a project is now in progress under a cooperation contract with CEA, Saclay.

The geometrical aspects of crack instability (in tubing) were studied in a continued effort to investigate through-cracks and to check the theoretical criteria of instability of part-through cracks.

Fatigue crack growth studies on austenitic steel specimens dealt specifically with the influence of two parameters; namely the frequency (on base and welded material) and the sodium environment. At their present stage, the tests give clear evidence of an increased growth rate when the frequency is lowered from high (2000 cpm) to low (~ 2 cpm) values, while welds seem to behave slightly better than the base material. As to the sodium influence, the results of the limited number of tests were in agreement with literature results to demonstrate a lowering by one order of magnitude of the crack velocity in sodium as against air at the same temperature (540°C), frequency (300 cpm) and load ratio (~ 0.3).

Structural aspects of fatigue crack growth were also considered, looking at the influence of the axial component of the load in through-cracked stainless steel tubes under cyclic pressure loading, and their behaviour under torque loading. The results showed a dramatic increase of the growth rate in presence of a compressive axial load. Moreover the growth rate was higher under torque loading in combined modes II and III than mode I. Both these results imply important theoretical and practical aspects which should be more thoroughly investigated in the future.

Coolant Thermohydraulics Studies Associated with Accidents

Basic Depressurization Studies

The utilization of the DHT-1 loop continued with the simulation of cold-leg and combined cold- and hot-leg ruptures. The experimental results were compared with the theoretical predictions of the GAAA KAPTOR code. The results, already published in 1975, can be summarized as follows:

- The delay of DNB occurring in conditions of flow reversal in the test section lies in the range of 0.3-0.7 sec, depending on the rupture size. When these delays are introduced into the KAPTOR calculations, one obtains excellent agreement between the measured and predicted "cladding temperature" and heat transfer histories.

The experimental programme of the thermal non-equilibrium studies sponsored by a collaboration contract with the BMFT finished at the end of 1975. Series of 35 flashing tests and 80 cold water injection tests were carried out in a temperature range of 200 to 320°C. The main results can be summarized as follows:

- Flashing tests: the half-value times of return to equilibrium lie between 10 and 150 milliseconds, depending on temperature and initial disturbance. The experimental results agreed well with a theoretical model based on a bubble growth law.
- Cold water injection tests: the half-value times are in the order of 0.5 seconds. The process is characterized by an initial condensation of vapour on the cold water and subsequent revaporization.

Blowdown Loop Project

The main achievements in this project are described in a special topic of this Report. See Mr. W. Riebold's contribution "Experimental Investigation of the Influence of PWR Loops on Blowdown".

Transient Boiling Heat Transfer in ECC Conditions

The determination of the DFB (Departure from Film Boiling) or quenching point is essential for the layout of the ECC system and the development of analytical rewetting models. It was therefore desirable to do some basic experimental work in simple geometrical conditions to check the existing physical models and heat transfer processes under real ECC conditions. In 1974 and 1975 the experimental facility was built up, the experiments were performed with the specified parameters, and the influence of such parameters as subcooling, initial temperature, pressure, flooding velocity were experimentally determined. The experimental results show that the main influencing parameter in the boiling quenching process is the local subcooling of the quenching coolant. A physical model is being developed to describe the film-boiling heat transfer in subcooled conditions until the DFB point, for all realistic ECC conditions.

Boiling Mixing in Fuel Rod Bundle Geometries

The investigation of the interaction and mixing effects between subchannels of fuel rod bundles should provide experimental data on the local distribution of mass flow, enthalpy and void fraction, so as to achieve a more precise DNB margin. Besides the measurements under steady-state conditions, it is also necessary to study the mixing process in transient conditions, e.g. during power transient or initial blowdown conditions. The work, sponsored by collaboration contracts with the BMFT and CNEN, consisted mainly in modifying the BOWAL loop and stepping up the power

supply for the loop to 3.6 MW DC. The 16-rod bundle BWR test section was developed in collaboration with CISE and has been mounted in the loop. It is also intended to develop a 16-rod bundle test section with PWR geometry. During the modification of the BOWAL loop a great deal of work went into development of the necessary measurement techniques, especially for the void fraction during transients where little experience was available.

Fuel Sodium Interaction – Tank Experiment

In the reporting period the test programme for which the tank facility was originally designed was completed.

Molten UO_2 at about 2850° (2, 3 and 4 kg) was dropped in a pool of sodium having initial temperatures of 350, 500, 630 and 700°C. Pressure records were taken at the wall of the tank and showed that only very small pressure bursts occur which increase from a few bars up to a maximum of 10 bars when the sodium initial temperature is increased. Particle size distributions were obtained for all tests. The analysis of these results shows that the assumptions made in the parametric calculation codes are pessimistic and that more realistic models of the mixing and fuel fragmentation procedure are needed in order to explain the experimental results.

Work started on the investigation of sodium entrapment phenomena. For this purpose some new equipment has been developed for injecting a small quantity of sodium into UO_2. A new computer code calculates the temperature and pressure fields in such a device.

The theoretical work was backed by a search of the literature on sodium and water boiling curves.

Fuel-Water Interaction, Tank Experiment

The new test facility for these experiments, sponsored by a collaboration contract with the BMFT, was built and tested and is now operative. It allows the melting of max. 4 kg core material which is dropped into a 300 l reactor tank filled with water, with a maximum operating pressure of 25 bars. It is planned to investigate the interaction of molten fuel and reactor structural materials (stainless steel, Zircaloy, Inconel) with water. The first series of experiments dealt with the interaction of stainless steel with water in the following conditions:

Steel weight	1500 g
Melt temperature	1600°C
Water temperature	20° and 80°C
Fall-height (melt to H_2O)	30 to 10 cm
Pressure	1 atm N_2
Gas content of water	saturated and degassed

Pressure, temperature and strain were recorded as a function of time.

These experiments showed only slight fragmentation and consequently the pressure rises were small (less than 1 bar).

UO_2/Na and Core Melt/H_2O Interactions in Channel Geometries

Core melt/coolant thermal interaction tests were performed with solid (~1450°C) and molten (~1600°C) stainless steel and water at ambient temperature and pressure. Under neither condition was any essential difference observed as regards pressure generation and interaction history. The pressure peaks measured downstream of the reaction crucible did not exceed 4 bars. Repeated coolant ejection and re-entry were observed. Fragmentation of the molten stainless steel surface was very slight.

A two-dimensional code to describe the fuel/Na interaction in a channel geometry was developed and tested with the experimental results. The calculated pressure peaks are far higher than those measured, while the theoretical prediction of the interaction pattern is in good agreement with the first UO_2/Na experiments.

The code is being modified so that it will also describe the interaction of H_2O and molten core material.

Basic Studies of Na-Boiling Thermohydraulics in Simple and Bundle Geometry

Four activities are covered by this heading:

- **Studies on liquid metal boiling under forced convection**

The aim of these studies, executed in collaboration with the CEA Grenoble, is to acquire further basic information on:

- flow redistribution during the transient from single-phase flow to boiling regime and two-phase flow pattern
- boiling heat-transfer and dry-out conditions
- pressure drop in boiling sodium two-phase flow.

Experiments were performed in a 6 mm tubular test section in order to measure these factors during both transient and steady-state boiling. The coolant velocity in the test section was varied in the range of 1 m/sec to 6 m/sec. The maximum heat flux at which boiling tests were done was 500 W/cm^2.

A computation code (ESSO = **E**bollizione **S**tazionaria **S**odio) was developed to evaluate the tests and to predict the pressure drop, dry-out and heat flux under liquid metal two-phase flow conditions.

- **Liquid metal boiling behaviour in porous blockage**

Qualitative investigations of the behaviour of porous blockages in static Na and in "natural convection" Na flow were carried out in order to assess the size of phenomena which have to be investigated and to plan a future programme on this subject. Tests were carried out in a tube blocked by a porous cylinder of 25% porosity, and in a 7 mm diameter tube blocked completely. The results of these experiments enabled a test programme for the investigation of boiling behaviour in realistic channel blockages to be defined.

- **Behaviour of gas in Na-loops**

The study of gas behaviour is focused on investigation of the solubility and separation of small quantities of argon gas in flowing sodium. The first step is to find and calibrate reliable detection devices. An ultrasonic detection device proposed by the UKAEA is being tested.

Experiments on calibration of the gas detection device were initiated. The first attempts to calibrate it showed that the test loop did not degas into the expansion vessel; this led to an unknown increase of the reference gas level. Further difficulties arose from cavitation in the by-pass valve which probably released dissolved gas into the measuring test section. Modifications to eliminate the sources of error on the hydraulic side are under way.

- **Behaviour of residual liquid film on fuel elements in the event of coolant ejection**

The experiments in the study of the liquid film remaining before and behind spacers after a coolant expulsion were terminated and the results were compared with those obtained on tubes without spacers.

Basic Analysis of Rod Bundle Thermohydraulics

This activity is fundamental, long-term combined theoretical and experimental research on coolant thermohydraulics in rod bundles. The object is to acquire knowledge on the detailed thermohydraulic behaviour of LMFBR subassemblies in the following anomalous situations:

- a cooling deficiency inside the subassembly due to a geometrical anomaly;
- a thermohydraulic transient due to a sudden deterioration of cooling or a rapid change of power.

The development of a mathematical model for computing three-dimensional velocity fields in rod bundles was started. New methods were developed for computing the transient temperature distribution in fuel rods and the coolant temperature transients in a single fuel channel. These methods will be essential parts of a new computation model for predicting the thermal response to loss-of-flow transients in LMFBR subassemblies with a transversely non-uniform power distribution.

Hydrodynamic experiments are now in progress to investigate the fundamental flow characteristics in the recirculation zone downstream of blockages.

Early Failure Detection

Thermohydraulic Noise Analysis

This work, which started in 1973 in close association with the activity described under the chapter "Basic analysis of rod bundle thermohydraulics", is expected to prove the possibility of detecting any anomaly in a subchannel of an LMFBR by measuring and analysing the temperature fluctuation at the exit of a subassembly. A model was developed to interpret the noise measurements on the basis of a stochastic theory of turbulence. It appears that the frequency analysis of the temperature noise is not sufficiently sensitive to allow identification of a blockage. However, analysis of the amplitude distribution seems to give more information on the blockage size and location. The experimental part of the work started with the development and testing of special detectors for the measurement of temperature fluctuation in water flows, and evaluations of the transfer functions of these detectors. Basic experimental studies were performed in an 8-rod linear bundle with water. The noise signals were analysed by several statistical signal-processing techniques. Preliminary tests were run with a 169-rod bundle and will be resumed after certain improvements to the test section.

Neutron Noise Analysis

Neutron noise analysis is considered to be a promising method for detecting the vibration of core components. Owing to the early closure of the zero power critical facility ECO in 1973, no further neutron noise measurements could be performed. The existing experiments were analysed in 1974, however, and the results obtained can be summarized as follows. A single ECO fuel element was included to vibrate with a frequency of 0.13 Hz and the oscillations were detected by neutron noise measurements obtained with three ionization chambers in three different positions. The correlation between fuel-element oscillations and neutron noise was very high and independent of the position of the element. Owing to insufficient instrumentation it was not possible to observe time delays in the cross-correlation function and it was not possible to localize the noise source by triangularization techniques.

Ultrasonic Emission

The main achievements under this head are described in a special topic of this report. See Mr. A. Lucia's contribution "On the Interpretation of Acoustic Emission Signals".

Reliability

During this period we have been involved in three areas of activity, namely, reliability analysis of complex systems, structural reliability, and data acquisition and processing.

In the first area the main achievement was the development of a method for assessing the probability distribution of accidental loads of internal origin (over-pressures, over-temperatures) in a reactor. The method consists in the combination of a fault-tree analysis for determining the probability of transient paths, and a deterministic analysis for determining the consequence of each path. The method, as far as the fault-tree analysis is concerned, is based on the AWE computer program, which uses a sensitivity approach. A detailed application of the method was carried out to determine the overpressure distribution in a PWR.

In the second area the main achievement was the completion of the COVAL computer program. The program finds the histogram or the distribution resulting from the combination of histograms or distributions and computes the interference between two histograms or distributions.

In the third area we mention two successful pilot studies. The first, applied to the safety analysis of an ESSOR loop, was designed to demonstrate the possibility of combining the fault-tree analysis, the "reliability categories" approach to safety (CNEN approach) and the operating experience on such a plant. The second study, carried out in collaboration with ENEL, was designed to "validate" the fault-tree modelling. The recorded availability of a conventional power unit was compared with the predicted availability based on a fault-tree and on reliability data found for the various components through a computerized operation data management system.

Theoretical Accident Analysis

Blowdown Theory and Codes

A survey was made of the literature and available codes on LOCA analysis, with special attention to the blowdown part of the accident. A critical analysis of the different approaches and the different physical models employed in blowdown analysis was performed. Sample calculations using RELAP 3, for both PWR and BWR reactors, were seen. Some typical results obtained were used for an extensive sensitivity study of the code THETA 1-B for the thermal behaviour of the cooling channels during blowdown. The CEA code DANAIDES was acquired and tested; the tests will continue after complete revision of the code by the CEA. As a result of the critical examination of blowdown models and codes, two main steps were taken:

- A new model was developed, based on flow equilibrium, for the thermohydraulic analysis of the primary circuit during blowdown. This is to overcome the difficulties inherent to formulation of the momentum equation in the nodal approach. This model has been translated into numerical equations and programmed as the NICKY code. The code has been extended to include both the pressurizer and pump model and is now dealing successfully with simple cases.
- An experiment on hydraulic oscillation in two-phase conditions was proposed, to elucidate the actual physical behaviour of a simple system, to collect reliable data to check the validity of the models available and, if the need arises, to provide the experimental basis for improved models.

Core Accident Codes

Important improvements were introduced into the COSTANZA code to make it more suitable for the Safety Analysis of the HTGR. This work was done under a collaboration contract with the OECD Dragon Project.

A model of the internal fuel block element was incorporated into the code: in this fuel concept the graphite block houses separately fuel channels filled with fuel cartridges and coolant channels in which the He flows. The new model simulates the assymmetric temperature distribution in the elementary cell by an appropriate choice of shells. The program was successfully tested against the two-dimensional heat-transfer dynamics code HEATRAN.

A second series of improvements was made in order to analyse the transient situation in the Dragon Reactor Experiment (DRE). The decay-heat part of COSTANZA, together with its neutronic and thermal steady state part, was coupled with the UK code TUBER to provide a proper description of the core thermohydraulics during the water/gas accident. The TUBER code was used to study the reaction behaviour of the steam with hot graphite: a special analytical solution of the component transport and reaction equations describes this reaction under in-pore diffusion conditions.

The other main activity was devoted to the initiation of a European code for the study of the hypothetical accident in an LMFBR (**W**hole Core **A**ccident **C**ode). It is ultimately intended to develop at the JRC Ispra a modular system in which all different physical models describing various events of the accident can be incorporated. The implementation of a modular system, based on the existing "File-Independent Calls" was initiated; and lastly, the VENUS and SAS codes were made operable on the JRC computer.

Work on the numerical methods for spatial reactor dynamics also continued; this activity focused mainly on the use of the splines function: a two-dimension and one-energy group structure was successfully tested.

Applied Informatics

H. Neu, G. Gaggero, J. Larisse, E. Perschke *

In the decision of the Council of Ministers of 14th May 1973, establishing a four-year Research Programme for the Joint Research Centre a specific programme on "Applied Informatics" is included which follows the main lines of earlier developments of CETIS (Centre Européenne de Traitement de d'Information Scientifique).

The work relating to this programme came under three principal headings:

- EUROCOPI (European Computer Program Information)**
- Information Science (integrated system for automatic documentation and translation)
- Methods and Systems for Computing (methodological help to computing).

The total budget allocated for the four-year programme is 6.05 million u.a., with a maximum staff allocation of 31 man years/year.

A breakdown of the manpower and the budget (excluding personnel charges and use of big installations) for the three actions is given in the following table 1.

Table 1

	Personnel in place man years/year		Budget (u.a.)	
	1974	1975	1974	1975
EUROCOPI	15	13	52,000	130,000
Information science	6	7	25,000	20,000
Methods and systems for computing	6	4	10,000	5,000
TOTAL	27	24	187,000	155,000

An Advisory Committee for Programme Management (ACPM-Applied Informatics) was established and met for the first time on November 19-20, 1974. Three further meetings were held in 1975.

* *Up to September 1st, 1975, Mrs. C. Mongini-Tamagnini was responsible for this programme.*

** *Formerly known as "COPIC" Computer Program Information Centre)*

• EUROCOPI (European Computer Program Information)

Introduction

In Europe, as in the rest of the world, the use of computers has grown rapidly during the past decade. Computer applications have advanced, many programs being written by software companies, computer manufacturers, universities, industries, and governmental bodies. Nevertheless, the development of new programs involves increasing costs and the promotion of software sharing is considered necessary.

For an efficient software exchange, the first requirement is complete information on the software available on the market; secondly, suitable ways to access programs must be available.

For these reasons, a scheme was started at the JRC in 1971 with the long-term aim of:

- promoting cooperation on a full European basis for a complete information service on scientific /technical software;
- improving program exchange, especially in those fields where European program libraries do not exist.

The short-term objectives of this scheme, known as EUROCOPI, were:

- to set up an experimental computerized data base on program information and to develop the necessary informatics tools;
- to organize a program distribution and program information dissemination service on an experimental but operational basis.
- the development of research and educational activities aimed at providing efficient support to the users of programs.

Activities of EUROCOPI

The EUROCOPI activities have been directed along the following lines:

Program Information Service

- Design and development of a conversational information storage and retrieval system

(SIMAS) for the management of the program-information data base.
- Development and maintenance of a comprehensive computerized data base on program information. Collection of program information is mainly based on the abstracts submitted by Program Libraries/Information Centres and by program authors/owners.
- Diffusion of information by issuing Program Indexes and by answering queries on specific subjects.
- Promotion of cooperation among European program libraries/programs information centres/user groups operating in the field of scientific and technical software in order to improve the exchange of information and finally the sharing of software within the European Community.

The actions to be undertaken in 1976 will include:
- the organization of regular meetings in which the European Program Libraries/Information Centres can compare their experience and define common courses of action;
- promotion of and participation in joint working groups for the development of standards for a program documentation system (abstracts, thesauri, etc.).

Program Distribution Services

- Operation of the JRC Program Library and of the European Distribution Agencies of SEAS (Share European Association) and I.U.G. (ICES Users Group). Setting up of other European Agencies of non-European Libraries to make easier and less expensive the acquisition of programs developed outside Europe.
- Promotion of action aimed at improving the portability of application software.

This action will include also:
- defining suitable recommendations and guidelines for scientific programmers, and diffusing them by means of courses;
- developing tools which can help in the adaptation of existing programs to new computers.

Research and Educational Activities, Users Support

- Maintenance of a dynamic library of programs on the JRC computing installation and support to users through direct advice and subject seminars and courses.
- Study of techniques for improving application software quality and portability.

Main Achievements, End 1975

The main achievements can be summarized as follows:
- The SIMAS system has been developed and successfully operated.
- A data base including about 3000 program abstracts has been set up and used for the information dissemination service.
- Several publications (Computer Program Indexes, Program Description Series) have been produced and distributed (more than 2000 distributions/year).
- A users community has been created with more than 500 member organizations.
- Cooperation agreements have been already established between EUROCOPI and various organizations, namely SIZSOZ (GMD, Bonn), PLU (Edinburgh Univ. U.K.), CPC Program Library (Queen's Univ. Belfast), C.S.A.T.A. (Univ. di Bari, Italy), SEAS (Share European Association), I.U.G. (Ices Users Group). Other agreements are near to completion.
- A consortium, called ECSIR (European Consortium for Software and Information Transfer in Research and Teaching), was formed in November 1975 among EUROCOPI, the Program Library Unit of Edinburgh, and the SIZSOZ project of the GMD, Bonn. The consortium is open to membership for bodies (Software Libraries, Information Services, Distribution Agencies, Users Groups) who are interested in library collections and services concerning software and related information on an European basis. With the purpose of bringing together those who would like to participate in setting up a work programme and to formulate proposals for future activities, the Consortium has started organizing a Conference to be held at Ispra in February 1976.
- A program distribution service with about 700 distributions/year has been put in operation.
- A library of about 100 programs running on the JRC computer is maintained and support is provided to users.
- The COREA system for remote access to the above library of programs has been developed.
- Research has been carried on and cooperation established in the field of integrated modular systems and problem-oriented languages (EUROCOPI has a seat on the Board of Directors of the European Session of I.U.G. and in the GENTRAN Development Committee).

Table 2 shows how many institutions were using the EUROCOPI services at the end of 1975 (approved by letters and requests).

We can say that after some years of activity, EUROCOPI service is well-established although not operating at full rate. The results obtained and the users' interest have proved the feasibility and the usefulness of an information network on computer programs having EUROCOPI as the point where information collected on particular subjects and/or a national basis can be assembled and redistributed.

Potential users can in this way easily get ex-

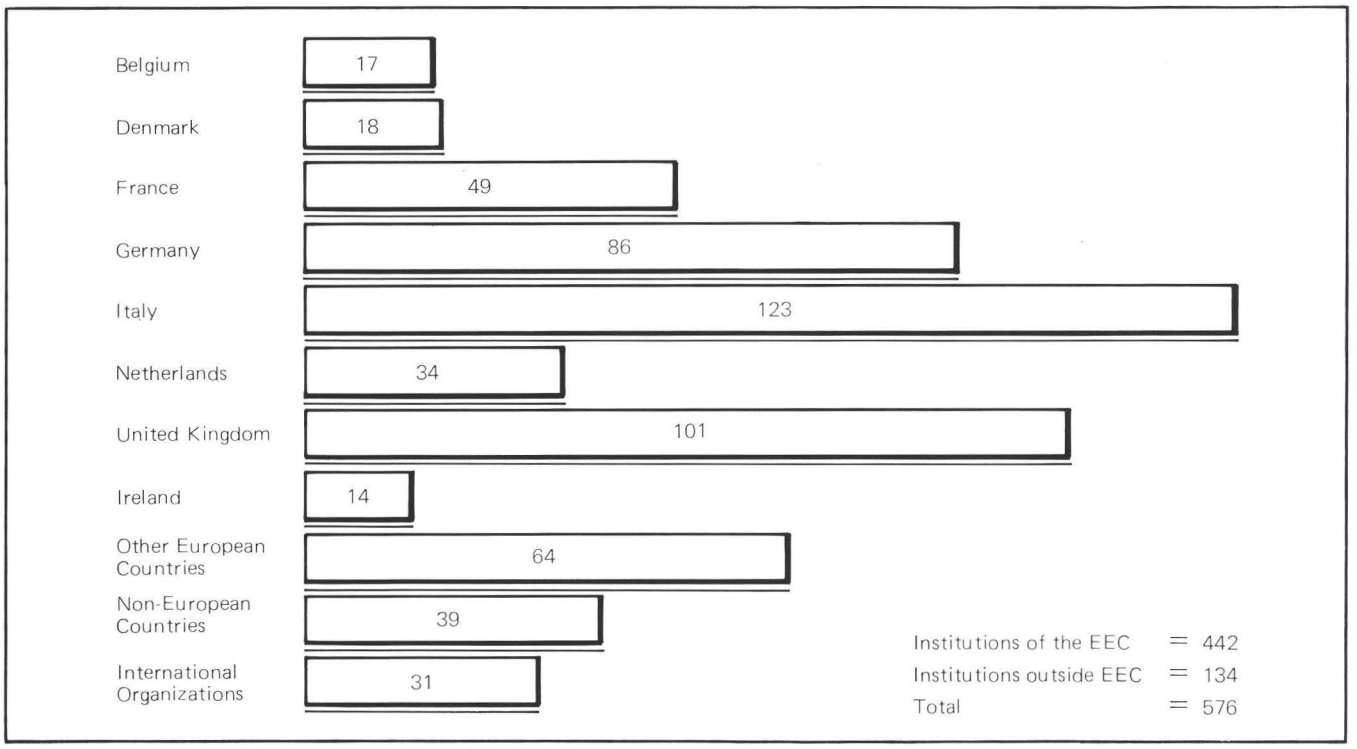


Table 2 Institutions Using EUROCOPI Services (1975)

haustive information on the available programs and rapid access to them.

EUROCOPI is now turning from a funded activity into a partly self-supporting service.

- **Information Science**

The objective of the project is the development and experimental evaluation of an integrated system for automatic documentation which provides automatic indexing, automatic query formulation, automatic thesaurus construction and advanced retrieval strategies with relevance ranking and feed-back.

The first part of the program period was mainly devoted to the implementation of the necessary informatics tools which were conceived as a generalized system for language processing: SLC—II (Simulated Linguistic Computer). This system is now fully operational.

As a first large-scale pilot application of automatic indexing in a real-life environment, INIS (the International Nuclear Information System of IAEA, Vienna) was chosen and the work is being performed in cooperation with the Directorate General for Scientific and Technical Information and Information Management, in Luxembourg (DG XIII). Under the cooperation agreement the whole of the informatics and methodological work is under the responsibility of Ispra, while the work closely related to the subject field, in particular the intellectual enrichment of the thesaurus, is to be done by DG XIII which has a long experience in nuclear documentation.

The preparatory work, such as the transformation of the INIS thesaurus for automatic processing and the design and implementation of the revised indexing algorithms, was to a large extent concluded by the end of 1975.

1976 will be devoted to an extensive evaluation of the system. For this purpose a cooperation agreement with IAEA is being prepared, in which the end-users of the INIS SDI services in the Member States will be asked to assess the pertinence of the responses to their queries as compared to previous retrieval results with manual indexing.

The work on automatic thesaurus construction proceeded slowly owing to lack of staff. In 1974-75 the subject was discussed in a doctoral thesis by a graduate of the University of Turin and at present one undergraduate and one postgraduate student of the University of Linz are investigating automatic phase generation and clustering techniques.

At the JRC the techniques developed for the automatic thesaurus construction are being applied to the material of Eurocopi and ESIS, in particular with the idea of standardizing their thesauri in view of a possible integration of these data bases into EURONET. This work is being done following the recommendations of the Advisory Committee for Programme Management (ACPM) to give methodological and informatics support to the data-base projects of the JRC. For this purpose contacts have been taken up also with ECDIN and CBR in order to analyse their needs and to define a coherent policy in this field.

Following the recommendations of the ACPM, the other parts of this project, in particular Machine Translation and Library Automation, were discontinued since the project was understaffed and no significant impact could be expected in these fields.

- **Methods and Systems for Computing**

The activities under this head are planned as fundamental research or development in order to place new tools, more powerful than the classical ones, at scientists' disposal in the framework of EEC projects, namely Environment, Reliability in Reactor Safety, Standard and Reference Materials, Hydrogen Production, Teledetection and so on.

The main topics treated during 1974-1975 were the following:

- Theory and application of models;
- Numerical analysis;
- Stochastic processes, Bayesian techniques, classification methods;
- Computer systems performance evaluation;
- Data base management.

The principal results achieved in the five subjects are described below.

Theory and Application of Models

This work deals with studies about mathematical models, using mainly differential or partial differential equations and simulation techniques. Special models were developed in aquatic and terrestrial ecosystems, zooplanktonic population dynamics, and chemical and tracer kinetics.

We have been studying the "models theory" both from the epistemological and the mathematical point of view in collaboration with the "Institute of Logic" of the State University of Milan, in order to have a deeper knowledge of the meaning of the mathematical models in these new fields. These approaches differ in several aspects from the classical applications in the field of physics.

Numerical Analysis

The studies concerned mainly applications and comparisons of variational and collocation techniques in order to solve boundary value problems.

Stochastic Processes, Bayesian Techniques, Classification Methods

In the important fields of Bayesian Techniques and Decision Theory, several seminars and courses were held in Ispra and outside in order to show the great suitability of these methods to such projects as "Standard and Reference Materials", "Reliability in Reactor Safety". A particular design of experiments was developed and used in the Standard Reference Materials project, which permits us to compare chemical and physical methods of measurement, using different standard deviations. We applied a Bayesian decision procedure, based on the estimated life-time of an expensive item, in order to determine the optimum time for replacement of the item.

In connection with the AGRESTE project (a study of the possibilities of remote sensing of earth resources), a software package developed at Pennsylvania State University, was kindly put at our disposal. These programs had been tested and classified according to a methodological criticism of the subject. This classification can be described as follows:

1) Discriminant Analysis: Here the problem is to assign a new object to a class or a group of objects with known characteristics.
2) Taxonometry: The division of a set of objects in homogeneous groups, using **a priori** defined rules.
3) Seriation: The task of finding an order relation existing in a set of objects.

This methodological activity was stopped from October 1974 until the end of 1975 because the team was working intensively on the exploitation of the results furnished by the Earth Resources Technology Satellite.

Computer Systems Performance Evaluation

In 1975 a new activity started concerning the use of mathematical techniques in order to increase the performances of the JRC computer centre. During this year, our main efforts were devoted to a state-of-the-art study, the results of which are reported in a paper requested by the ACPM for Applied Informatics, and the preparation of a proposal for the new multi-annual programme.

Data Base Management

The most important work was concerned with the study and evaluation of the Information Management System (IMS) of IBM using PL1 and COBOL languages, and with the setting up of a pilot study in administrative and management fields.

The choice was prompted by the need to create a "nucleus of competence" in the above mentioned fields.

The results of the work are the following:

- a thorough knowledge of IMS of the IBM was acquired;
- the implementation of the pilot study concerning a Data Base containing medical data (professional risks and medical examination for the

personnel of the JRC) is functioning in batch mode. Several aims of the study have already been fulfilled;

- the progress of the work was remarkably slowed-down by unexpected incompatibilities between the PL1 compiler and the version of IMS implemented at our installation. Consequently the PL1 was abandoned in favour of COBOL which has given satisfactory results;
- our collaboration with the Italian GUIDE Data Base Working Group continues regularly.

Information Analysis Service Programme

R. Nicks

The "Information Analysis Service" activity, a specific item in the JRC multiannual programme, started at the beginning of 1972. It consists of service activities related to specific areas in the nuclear field and is intended for engineers engaged in design problems and research. The services offered are based on the competence built up during the research work of the last years.

Three Information Analysis Services have been set up, namely:

- ESIS, European Shielding Information Service
- INDAC, Integral Nuclear Data Centre
- ESMIS, European Structural Mechanics Information Service

A layout of the budget (excluding personnel charges) and manpower directly allocated for the three actions covered by this programme is given in the following table:

Action	Staff man-years for 1974 and 1975	Budget	
		1974	1975
ESIS	10	25,000	36,000
INDAC	10	23,000	35,000
ESMIS	7	2,000	3,000
TOTAL	27	50,000	74,000

ESIS

During 1974 and 1975 the ESIS activities proceeded along the following lines:

- Code Assessment
- Nuclear data
- Experimental activities
- Technical consultation
- Information diffusion

Code Assessment and Nuclear Data

In design situations the shielder is often faced with the problem of thick bulk shields (large radiation attenuation) followed by heterogeneous configurations containing tolerance gaps, straight or bent ducts etc., which give rise to radiation streaming. Whereas a valid approach to deep penetration problems relies on numerical transport codes like DOT, for streaming through ducts and voids, the Monte Carlo method (used in codes like MORSE) is most appropriate. Consequently the chain DOT-DOMINO-MORSE has been implemented at Ispra and extensively tested by EURACOS measurements on a mock-up characterized by deep attenuation properties and complex geometry. A MORSE–Albedo subroutine package for treating neutron and photon propagation in large voids has also been established; albedos have been calculated by ANISN.

The assessment compaign based on ANISN, DOT, MORSE, SABINE , MERCURE, SCORE has come to an end. Therefore ESIS switched over to the study of sophisticated European codes, for instance the French Monte Carlo Code TRIPOLI. As a first step this program was implemented and compared with a test problem of known solution. After the positive conclusion of this test which demonstrated the code's extraordinary capability for handling deep attenuations, the ESIS staff began preparation for a workshop on TRIPOLI to be held in 1976.

Sensitivity studies by SWANLAKE constitute one of the keys for providing a rational guidance in satisfying cross-section requirements. SWANLAKE is a 1D sensitivity code which calculates the relative variation of a response function for a one percent cross-section variation. The program was been implemented at Ispra and applied to iron cross-sections. The results of these calculations were presented at the Third Benchmark Meeting at Paris, 7-10 October 1975.

Integral checks of iron group cross-sections were made using relatively high energy neutron sources like ^{252}Cf fission neutrons; experimental results became available from INR–Karlsruhe, where neutron leakage spectra were measured from various iron spheres surrounding a ^{252}Cf source. Calculations were done (in collaboration with the Shielding Group of the University of Stuttgart) to check the standard EURLIB group data set of iron, which had been generated from ENDF/BIII. Iron group cross-sections from the newest ENDF/BIV data were also processed, so that all effects resulting from the newest point data evaluated can now

be studied in detail.

Using the nuclear data from ENDFB, POPOP, and the GAM-II files a coupled neutron-gamma library for 30 elements and nuclides was set up, together with some auxiliary codes for retrieving, collapsing and plotting. The library and the subroutines are available under the name EL4.

Experimental Activities

Because of the shutdown of the reactor Ispra 1, it was decided to transfer the shielding irradiation facility EURACOS to the TRIGA reactor of the University of Pavia. In the initial phase the EURACOS II will be operated at a power of 30 watts. During 1974 the designing of the new facility was accomplished, and in 1975 the main components (irradiation tunnel, mock-up) were constructed and transferred to Pavia. The facility is scheduled to start up at the beginning of 1976. In the second phase the converter power will be raised to 300 W. The first experiment to be performed concerns neutron propagation in an iron block ($1.5 \times 1.5 \times 1.5\ m^3$), in the context of the Common Benchmark Experimental Programme executed by the Shielding Groups of Winfrith, Cadarache, Karlsruhe, Mol, Casaccia and the University of Tokyo.

Technical Consultation

Besides the current consultation given for the use of particular codes and libraries (DOT, MORSE, SABINE-3, MERCURE, EL-4), a number of studies and calculations were carried out in support of the specific needs of European organizations. In particular these studies concern calculations of neutron streaming along the annular gap of the PEC-reactor by DOT-DOMINO-MORSE, and the calculation of angular photon spectra and dose rates in iron shields near thin and/or thick sources (study made for the German board of Radiation Protection).

Information Diffusion

ESIS decided to establish a shielding data bank in order to speed up access to and retrieval of shielding information. The bank contains bibliographic items obtained by weekly scanning of periodicals, reports and books. At the present time some 1500 bibliographic references have been introduced.

The publication of the ESIS Newsletter proceeded according to schedule: eight Newsletters were produced, with specific contributions from:

- IKE (Institut für Kernenergetik) University of Stuttgart
- KWU (Kraftwerkunion) Erlangen, Germany
- JAERI and Mitsui Shipbuilding and Engineering Co., Japan
- SKODA Nuclear Power Construction Department, Plzen, Czechoslovakia
- UKAEA, Winfrith, United Kingdom

Two special issues of the ESIS Newsletter concerning shielding benchmark experiments were also published.

INDAC

Theoretical Activities

As specified in the general programme, INDAC's theoretical activities deal with nuclear data assessment for radiation shielding applications. In particular the following three main items have been treated:

- Nuclear data evaluation and model studies for γ-ray production cross-sections
- Retrieval and processing of nuclear data for reactor shielding applications
- Sensitivity studies in three-dimensional benchmark experiments.

Nuclear Data Evaluation

This work primarily deals with the calculation of activation and capture cross-sections and the spectra of emitted particles, in particular γ-rays, resulting from neutron reactions.

After comparing the capabilities of different computer programs doing similar jobs the STAPRE program was chosen for our own purpose. It is the only one which conserves energy, spin and parity in a nuclear reaction. It was developed at the "Institut für Radiumforschung und Kernphysik" (IRK) at Vienna. This program calculates reaction cross-sections using the statistical and pre-compound model. It is, however, not very suitable for the calculation of neutron capture cross-sections since one does not get the excitation functions for a reasonably fine energy mesh of the incoming particles. But the precise calculation of capture cross-sections is important for different reasons: for instance, by comparison with experimental data one can test the gamma-ray strength functions used today to determine the prompt gamma spectra and the "gamma competition" in the reactions (n,n'), (n,2n), etc. In the case of many isotopes there are very few measurements for all these quantities except the capture cross-section, and thus the evaluation must rely heavily on model calculations.

For this reason the CAPTRE program was developed by M. Uhl at the IRK, in collaboration with INDAC; it calculates the capture reaction with the statistical model taking into account spin and parity conservation. The primary gamma transitions are calculated applying the

width fluctuation correction; the following gamma decay is treated by the cascade model used in the STAPRE. The CAPTRE program yields not only the activation cross-sections, but also the intensities of the primary gamma transitions, the prompt gamma spectrum and the average gamma multiplicities; and in addition the incorporating energy can be varied in very small steps. An application of this code to the reaction Ba^{138} (n,γ) Ba^{139} has been carried out and compared with experimental data.

The goal was to study the dependence of the results on the model paramters and to fix their values approximately. This is of importance especially for those reactions for which there are few or no measurements available, so that they have to be evaluated by model calculations.

To simplify evaluation work further, the following two items were dealt with recently:

- incorporation of the IRK programs into a least-squares fitting procedure to adjust parameters and
- modification and extension of the IRK programs to calculate the whole evaporation chain in a single program run, starting from the first compound nucleous; this new modified version, called MODESTY, has been completed. It was presented at the IAEA Consultants Meeting.

Data Retrieval and Processing

In collaboration with the NEA-CPL, the retrieval codes PLOTFB, PLOTF4 were converted from the CDC6600 computer system at BNL to the Ispra IBM 370/165-CALCOMP system. Moreover other retrieval codes such as CHECK4, CRECT4 and RESEN D were implemented on the IBM 370 system. All these routines are available through the NEA-CPL library service.

At a later stage, again in collaboration with the NEA-CPL, much work was devoted to the implementation of the Programme-System AMPX. After extensive tests a coupled neutron-gamma library was generated from ENDF/B3 for the following isotopes: Fe, H, Al and Na (99 neutron and 19 gamma energy groups in a P_5 approximation). For H and Al the γ-production cross-sections had to be substituted from the DLC-7D library. The generation of coupled neutron-gamma libraries from ENDF/B4 data files has also been started. Coupled neutron-gamma libraries produced by AMPX from ENDF/B4 will substitute step by step the POPOP4 library used in ESIS shielding calculations.

Furthermore similar libraries have been processed in an interlaboratory effort. As requested by the Shielding Benchmark Experiments Meeting at Ispra (April 1974) the "Institut für Kernenergetik" of the University of Stuttgart (IKE) together with INDAC, established a standard energy group structure (EURLIB-Standard Structure) to be used for the interpretation of the iron benchmark experiments. (see ESIS-Newsletter Nr. 12, January 1975, page 1, Standard Neutron Energy Group Structure for Shielding Benchmark Experiments). Coupled Neutron-gamma libraries for Na, H, Al, C, O, Ni and Cr have so far been compiled.

Sensitivity Studies

In the recent past much emphasis has been given to sensitivity studies to establish priorities in the long lists of requests for cross-section measurements and evaluations.

So far most sensitivity studies have been carried out for one-dimensional problems. In shielding calculations, however, where ducts and other heterogeneities are of primary importance, two- and three-dimensional sensitivity calculations are being increasingly requested. Since shielding calculations for these problems are almost exclusively done by Monte Carlo techniques, the associated sensitivity studies also require the same methods. One of the main problems, in this context, is the study of space-dependent sensitivity factors in widely varying geometries and material compositions. For this reason, estimators allowing the calculation of fluxes at points will have to be introduced. In the present approach one solves the "forward equation" and samples the contributions to the different detector points from each collision point simultaneously using the once-more-collided point estimator procedure. The sensitivity factors themselves are calculated by correlated sampling where the same tracks are used in the unperturbed and the perturbed case. Since in this technique the perturbed case has to use the collision density functions of the unperturbed case, additional weight factors must be introduced to obtain an unbiased result. This concept has been combined with a regional-dependent "expected leakage estimator" to improve sampling in deep penetration problems.

The mathematical formulation of the problem is described by H. Rief. The method was incorporated into the TIMOC program and a number of test examples have so far been calculated. They deal mainly with one-dimensional problems which can be compared with equivalent ANISN-SWANLAKE sensitivity calculations.

Integral Cross-Section Measurements in Fast Reactor Spectra

It was the aim of this experimental activity to determine the capture cross-sections of structural materials for fast reactors (Fe, Cr, Ni, stainless steel), averaged over the energy interval from 100 eV to 100 KeV, where the present knowledge of the corresponding differential cross-sections is unsatisfactory.

The work was carried out under a collaboration agreement among JRC Ispra, CNEN and AGIP NUCLEARE. The experiment was performed in the RB-2 reactor (property of AGIP Nucleare, in Bologna, Italy) converted into a fast--thermal coupled facility. The fast test zone consisted of a quasi-homogeneous mixture of UO_2 (^{235}U/U 93%) and graphite particles, loaded with B^{10} to k-inf = 1.

The test zone was surrounded by a buffer zone, consisting of an annular array of MTR type fuel plates (U^{235}/U 90%) and graphite wedged slabs.

The experimental technique used was the void--null reactivity method (PCTR) coupled to the reactor oscillation method. The first part of 1974 was spent in completing the fabrication of the mechanical components of the experimental facility and in assembling and testing the instrumentation set-up (measuring lines for pile oscillation experiments, spectral index determinations by fission chambers with various spectrum-sensitive coatings, B^{10} capture determinations, etc.).

In parallel a study was carried out to fix the optimum specifications for the homogeneous mixing of the particles in the test zone.

The new fast-thermal facility RB2/TV achieved its first criticality in September 1973, with a fast zone loading around 9 kg of ^{235} U. After a series of safety tests the reactor was ready for measurements at the end of 1973.

The experimental work carried out can be summarized as follows:

- Testing and refinement of the experimental methods, in order to maintain the experimental error within the limits set in an "a priori" error analysis performed for the whole experiment;
- Null-reactivity measurements for the determination of the B^{10} content in the test sample yielding a zero reactivity signal (i.e. the "null reactivity composition"). Two independent measuring lines were used in order to reduce the change for systematic errors.

The following test-medium compositions (in terms of atomic ratios) were investigated:

a) C/^{235} U = 150, Fe/C = 0 (two samples with different heights, to put into evidence delayed neutron effects).
b) C/^{235} U = 110, Fe/C = 0.4
c) C/^{235} U = 115, Fe/C = 0.8 (to show, by comparison with b), the effect of Fe content on the neutron spectrum)
d) C/^{235} U = 110, Cr/C = 0.4

- Spectrum index determinations by miniature fission chambers with deposits of ^{240} Pu, ^{239} Pu, ^{238} U, ^{235} U. A detailed spectrum index mapping over the whole test zone was performed through axial and radial scans, so as to compare the real spectrum behaviour with the ideal asymptotic behaviour.
- Determination of the ratio ($\bar{\sigma}_C$ $B^{10}/\bar{\sigma}_f$ ^{235}U) in the test samples, by B^{10} and ^{235} U chambers.
- Determination of the "reactivity worth" for Fe, Ni, Cr, B^{10} and stainless steel, by the reactor oscillation method.

The theoretical work in support of the experiment can be outlined as follows:

- Calculation of k-inf for the test-sample media by a 27-group ANISN run. The cross-section libraries used were: ENDF/B-1, 2, 3 and UKNDL. The group averaging codes used were: PRAVDA (based on the ABBN formalism) and MC-2.
- Calculation of effective cross-sections in the test samples by a 27-group ANISN run, with axial correction factors obtained by 10-group diffusion calculation.
- 2D, 10-group diffusion ALCI calculation of the reactor.
- Calculation of the spectrum mismatch and leakage correction by a 10-group, 2D diffusion code (ALCI) based on the Oldekop formalism.

The following table gives a summary of the results obtained for Fe (values of the ratio ($\bar{\sigma}_C$ Fe/$\bar{\sigma}_f$ ^{235}U) averaged over the considered spectrum (test sample b)).

	ENDF/B-3 PRAVDA	END/B-3 MC-2	ENDF/B-1 MC-2	CADA-RACHE 3
Calculated value	$.359\times10^{-2}$	$.465\times10^{-2}$	$.423\times10^{-2}$	$.299\times10^{-2}$
Measured value	$.270\times10^{-2}$ ± 20%			

The experimental result was inferred from a preliminary analysis of the data and could be somewhat modified in the future; the experimental error should also be reduced through the refinements now being made to the data analysis.

From the table it appears that the current cross-section libraries overstimate the Fe capture in the 100 eV-100 keV energy region. There are also indications (from other sources, not quoted here) that the ENDF/B-3 data overstimate the ^{235}U fission and underestimate the ^{235} U U235 capture in the same energy range.

ESMIS

The activities of ESMIS were carried out in the field of:

- pressure vessel analysis
- application of the finite element method (FEM) to Linear Elastic Fracture Mechanics

Pressure Vessel Analysis

The LWR pressure vessel work in the JRC started in 1972 as a collaboration between the Commission and German TÜV organizations. It evolved towards systematic bench-mark calculations by means of 3-D FEM analyses of current designs of LWR pressure vessels and in particular feedwater nozzles (PWR, BWR) and pump nozzles (BWR). The accent has been on the accuracy (convergence) of different discretizing schemes and to this end we wrote scheme automatic mesh generation programs.

- EURCYL 1 (BWR nozzles)
- EURCYL 2 (BWR, PWR nozzles)
- EURPUMP (Pump nozzles)
- EURCOCK (integrated nozzles)

In particular, analyses have been carried out concerning:

- Bruensbuettel BWR (TÜV Hamburg)
- Philippsburg BWR (TÜV Baden)
- Neckarwestheim PWR (TÜV Stuttgart)
- Krümmel BWR (Breda SA, Milan)
- Danish BWR (DAEC, Risø)
- Belgium BWR (Cockerill, Liège)

The results of these analyses have been summarized in various papers.

FEM Applications to Linear Elastic Fracture Mechanics

As a natural and technical continuation of the ESMIS pressure vessel work, during the present reporting period the presence of hypothetical cracks in pressure vessels were included in the analyses with the aim of showing that 3-D thermo-elastic crack problems can be analysed economically by means of FEM. The analyses of 3-D crack problems were found to be most conveniently carried out with the FEM substructuring technique. We applied the method to thermo-elastic fracture mechanics problems, for hypothetical corner cracks in BWR nozzles and for hypothetical surface cracks in the beltline of the vessel as well as for the LMFBR primary circuit. Mesh generating was done by automatic mesh generation programs.

- EURCRACK 1 (corner cracks in nozzles)
- EURCRACK 2 (surface cracks in plates)

Training and Education

R.Misenta

The "Training and Education" Division organized

- in 1974 a series of four one-week courses on "Safeguards and Nuclear Material Control" for assistant inspectors of the Safeguards Directorate of the European Commission, Luxembourg, and the first four Ispra-Courses with a total duration of 7 weeks;
- in 1975 nine Ispra-Courses with a total duration of 12,5 weeks;
- and prepared during the year 1975 the programme of Ispra-Courses for 1976.

The four Ispra-Courses held in the second half of 1974, with a total duration of 7 weeks, were attended by 96 persons from various organizations and firms.

The experience of 1974 and 1975 has shown that:

- industrial and state organizations are interested in courses offered by the Ispra-Establishment, as is shown by the statistics regarding participants;
- it is possible to cover the current expenses of the courses, e.g. publicity, expenses for invited lecturers, material for the lecturers' notes, etc., from the incoming participation fees.

Series of Courses on "Safeguards and Nuclear Material Control" – 1974

This series of four one-week courses for assistant inspectors of the Safeguards Directorate of the European Commission was held in Luxembourg and at Ispra.

Luxembourg, 4-15 February 1974

1) Nuclear Fuel Cycle and Nuclear Material Control Systems
2) Physics, Health Physics and Statistical Methods

Ispra, 25 March – 5 April 1974

3) Non-destructive Assay in Nuclear Safeguards
4) Chemical Assay and Sealing and Identification Techniques in Nuclear Safeguards.

The courses were attended by about 20 adjoint inspectors of the Safeguards Directorate of the European Commission.

The lectures of the first courses were given by staff members of the Safeguards Directorate and lecturers invited from the European nuclear industry. The lecturers of the last three courses were given by staff members of the Ispra-Establishment.

Ispra Courses 1974

After careful preparation of all the organizational aspects and administrative procedures, the first courses for people outside the JRC were advertised in summer 1974.

Series of Three Courses on "Radiological Protection"

After an analysis of the situation and the possibilities of the Establishment it was decided to prepare a series of courses on Radiological Protection and to offer these series under the patronage of the "Associazione Italiana di Fisica Sanitaria e Protezione contro le radiazioni". The courses use the broad experience which the JRC "Health Physics" group has acquired by its work with the reactors Ispra-1, ECO, ESSOR, and minor nuclear installations over a period of more than 10 years.

The series consisted of three-week courses in the Italian language

- Fondamenti di Radioprotezione
- Radioprotezione nelle applicazioni mediche ed industriali delle radiazioni
- Radioprotezione negli impianti nucleari

Every course was attended by 20 participants.

Course on "Structural Reliability"

For this one week course on structural reliability we used the experience acquired by a group of scientific and technical staff members working in this field which is mainly related to the programme on reactor safety.

Ispra-Courses 1975

The following courses were held during 1975:

- a two-week course on "Safeguards and Fissile

Material Control" with 33 participants, including 15 from the Safeguards Directorate (Luxembourg);
- a series of two courses on "Il Sistema ICES", in Italian, lasting three and four days respectively, with a total of 18 participants;
- a one-week course on "Systems Reliability" with 24 participants;
- a series of three two-week courses on "Radiological Protection", in Italian, with a total of 54 participants;
- a one-week course on "The Hydrogen Energy Concept", with 35 participants;
- a one-week "Advanced Seminar on Fracture Mechanics" with 74 participants.

The courses on "Safeguards and Fissile Material Control" and the three courses on "Radiological Protection" were revised editions of the corresponding 1974 courses.

The series of two courses on "Il Sistema ICES", in Italian, were organized in collaboration with "Centro Studi ed Applicazioni in Tecnologie Avanzate (C.S.A.T.A.)" Bari. The courses dealt with the application of the ICES-STRUDL sub-system for the design of mechanical structures and described the language and techniques used in the ICES–System.

The course on "Systems Reliability" treated the various aspects of components and systems reliability: e.g. data collection and processing, probability assessment and optimization techniques.

The course on "The Hydrogen Energy Concept" which was focused on hydrogen as an energy carrier gave a technical perspective of this rapidly-emerging field and treated the entire hydrogen energy cycle from production to end-use, i.e. hydrogen production, storage and transmission, handling implications, hydrogen utilization in some prominent domains.

The "Advanced Seminar on Fracture Mechanics" was organized in collaboration with the German Working Group on "Bruchvorgaenge" the French Working Group on "Fragilité – Rupture" and the Dutch Contact Group on "Breukmechanica". The Seminar helped to improve cooperation and exchange of facts and ideas in three main fields of fracture mechanics, which were selected in view of their large impact on practical application and their very fast evolution elasto-plastic fracture mechanics, dynamic fracture phenomena, and fatigue crack propagation.

The nine courses, with a total duration of 12.5 weeks, were attended by about 250 people from various organizations and firms.

Programme of Ispra Courses 1976

During the second half of 1975 we prepared the programme Ispra- Courses 1976, comprising 16 courses or seminars with a total duration of about 20 weeks.

The subjects of the courses and seminars have been chosen according to the degree of interest they present to various organizations and groups in the European Community countries and the experience and competence which the JRC Ispra has acquired in these fields, especially during the period following the adoption of the new multi-annual programme in 1973.

The lecturing staff at the courses and seminars is composed of JRC staff members and invited lecturers from European research centres or associations, universities and industry.

Some of the courses and seminars announced are organized in collaboration with other European organizations.

The following courses will be held in 1976:

A. Repetition or revised editions of previous courses

Safeguards and Fissile Material Control
- Safeguards in Nuclear Plants
- Techniques for Fissile Material Control

Radiological Protection
- Fondamenti di Radioprotezione
- Radioprotezione nelle applicazioni mediche ed industriali delle radiazioni
- Radioprotezione negli impianti nucleari

Reliability Engineering
- Systems Reliability
- Structural Reliability

B. New Courses

Environment
- Air Pollutant Modelling
- Urban Air Quality Management
- Pollution Ecology in Fresh Water

Computer-Aided Analysis of Structures Using the ICES-STRUDL II System

Advanced Physical Techniques in Structural Biology

Nuclear Merchant Ships
- Introduction to Nuclear Engineering for Ship Propulsion
- Technical and Economic Aspects of Nuclear Merchant Ships

Advanced Composite Materials

Physics and Calculational Methods for Shielding

Two of the courses on "Environment" will treat technical questions of air management in urban regions. This series of courses is intended to give urban and regional planners, health engineers and technicians interested in air quality management a comprehensive survey on such subjects as:

The seminar on "Pollution Ecology in Fresh

Water" will review various aspects of the ecology of pollution in fresh water environment.

The course is intended to give urban and regional planners, health engineers and technicians interested in air quality questions a comprehensive survey on such subjects as:

- instruments and networks for urban air quality monitoring and control systems.
- simulation of pollutant dispersion by tracer techniques and wind and water tunnels
- statistical models, diffusion and stochastic models for pollutant dispersion.

The course "Aided Analysis of Structures Using the ICES-STRUDL II System" will illustrate the structural analysis capabilities of the ICES subsystem STRUDL II. It is intended to assist engineers working in various fields such as mechanical, civil, nuclear and aeronautical engineering in the use of advanced data processing tools.

The Summer School on "Application of Advanced Physical Techniques in Structural Biology" is sponsored by the Commission of the European Community and organized by the University of Leiden in collaboration with and at the JRC ISPRA. It offers a survey of the physical techniques which are relevant to molecular biology to-day for physicists, biophysicists biochemists and biologists.

The two courses on "Nuclear Merchant Ships" are organized in collaboration with "GKSS" Gesellschaft fuer Kernenergieverwertung in Schiffahrt und Schiffbau, Geestacht. The course "Introduction to Nuclear Engineering for Ship Propulsion" is intended to give engineers and physicists involved in ship design and construction or operation, and introduction to the various fields of nuclear ship propulsion systems. The Seminar on "Technical and Economical Aspects of Nuclear Merchant Ships" is designed to satisfy the interests and needs of both technical and managerial personnel interested in the technical and economic aspects of nuclear merchant shipbuilding and operation and of sea transport planning

The Seminar on "Advances in Composite Materials" organized in collaboration with "Centro Materiali Compositi" Naples, Italy, will review technological advances made in composite materials during the recent years. It will deal with mechanical and physical properties, designing for structural and non-structural applications, methods of fabrication and evaluation of advanced composite materials consisting of polymer and metallic matrices and filaments, fibres and whiskers of various chemical natures.

The Course on "Physics and Calculational Methods for Shielding" treats the various aspects of radiation shielding and the calculational methods for the design of shields for reactors, accelerators or transport containers for radioactive material.

All courses planned for 1976 were advertised, mainly in the member countries of the European Community, in January 1976.

European Informatic Network

J. Pire

This project represents the Commission's participation in COST Project 11, the aim of which is the construction of a pilot mesh-network and its utilization for the study of the technical, economic and management requirements involved in coordinating the work of different types of computers cooperating in the solution of a problem.

An agreement at government level was signed at the end of 1971 by France, Italy, Norway, Portugal, Sweden, Switzerland, the United Kingdom, Yugoslavia and the European Atomic Energy Community for the design and construction of the telecommunication sub-network. The agreement was signed by the Netherlands in 1974.

A computer network composed of five centres was also decided upon. These centres are:

- IRA (Institut de Recherche en Informatique et Automatique) Rocquencourt – France
- POLITECNICO DI MILANO, Milan – Italy
- EIDGENOESSISCHE TECHNISCHE HOCHSCHULE Zürich – Switzerland
- NATIONAL PHYSICAL LABORATORY Teddington – United Kingdom
- CETIS (Joint Research Centre) Ispra, for the Commission

Because of the delay in ratification it was not possible to start this activity until 1972.

In spite of the delay all the countries concerned, together with the Commission, have appointed their representatives to the Management Committee.

The specifications were drawn up for the telecommunication sub-network and tenders for its construction were invited. A contract with the SESA-LOGICA consortium was signed in September 1974. This part of the project is scheduled for completion in March 1976.

The studies in the nodal centres suffered the consequences of these delays, owing to the complex and international nature of the project. Up to now the work has dealt with strictly related subjects such as establishment of standards, definition of the basic and medium level protocols between the computers and development of the relative computer programs; but the tests cannot be effectively carried out until the network is physically connected up in 1976.

Standards and Reference Substances

R.H.Gillot, H.Laurent

In 1974-75 our laboratories developed and extended the activities officially undertaken during 1973 and at the same time assembled equipment more specifically suited to the needs of a programme which is highly demanding from the point of view of precision and accuracy. While continuing their experimental work, various specialists of the Ispra Establishment, supplemented by specialists from the Geel and Petten Establishments, made a significant contribution to the definition of a broad European programme to be carried out in the Community (indirect action) and Commission laboratories (direct action).

Furthermore, the Ispra staff put a great deal of work into the definition of new activities for the JRC Petten Establishment (Netherlands). It has been proposed that a part of this Establishment be appointed to do work on the chemical characterization of organic substances, in the context of an enlarged Standards and Reference Substances' programme. A formal proposal has been submitted to the Council.

Our activities are divided under four headings, each covering a certain number of subjects:

- Support to the CBR secretariat
- Support to the Commission Departments
- Reference Materials and Chemical Analysis
- Reference Materials, Physical and Technological Properties

Support to the BCR Secretariat

Various staff members and specialists of the JRC devote all or part of their time to the preparation and follow - up of a "European programme". According to their fields of competence, they lead and/or take care of the secretariat work for Working Parties whose composition and objectives have been considerably enlarged in recent years. At the end of 1975, a total of 54 groups of experts were operational and Ispra provides the scientific secretariat of 30 of these groups.

In addition to the foregoing, various activities of general interest were pursued during the year:

- "guide book" of addresses of users of reference materials
- "data bank" on reference materials and organizations concerned with these products
- Information bulletin
- Applied statistics

Guide Book

After a limited distribution of a provisional edition, the Division distributed about 2000 copies of the first edition of this document.

Data Bank

In connection with the setting-up of an Information Bureau, the Division started to compile a computerized data bank which could eventually be linked up with a European information network (COST Project 11). A detailed description of this bank was communicated in 1975. So far we have stored:

1500 addresses of suppliers and users of reference materials

9800 different existing reference materials with their characteristics,

269 names, addresses and functions of national experts involved in the CBR action.

During 1976 the Division will continue to improve the system and to store and up-date the data already in its possession. The direct link between a terminal at the BCR secretariat in Brussels and the Ispra computer is already operational. It is now possible to hold a remote dialogue between the user and the bank.

Information Bulletin

After examining different mock-ups prepared at the Centre the ACPM recommended that the BCR should publish a simplified version of this bulletin, including in particular:

- information on the various BCR activities,
- information on events involving activities linked to those of the BCR,
- bibliographic lists of publications dealing with the preparation, certification and use of reference materials,
- annual index of these lists.

So far we have selected some 1500 references

and summaries of papers, obtained by checking about 55 reviews and periodicals and from 24 abstracts journals and descriptive bulletins (some 2500 reviews). It is obvious that we are still far from covering all the literature which might be of interest. The selected papers are now regularly listed automatically by the KWIC systems.

Applied Statistics

This activity is essentially used for the comparison of results obtained in analytical exercises and for comparative measurements and certification of proposed reference materials [5]. A part of our effort has been devoted to the selection of the best statistical tests, the application of a non-parametric test (Krusqual-Wallis) and the development of a data set. After discussions with national specialists, it seems that the Aspin-Welch technique is of considerable interest, but the question of its cost (mainly computing time) remains open.

Up to now, our techniques have been applied to various problems:

BCR problems

- certification of reference materials for traces of O_2 in Cu, Pb, Zr, Ti and Mo,
- certification of "commercial" elements in Zn, Cu, Pb and Sn ores in concentrates,
- certification of various elements and calorific power in 4 coke samples,
- evaluation of analytical methods for the determination of different chemicals in an atmospheric powder sample,
- evaluation of viscosity measurement data in 4 oil samples.

Support to the Commission

- evaluation of the methods for fertilizer analysis,
- evaluation of the methods for determination of casein and of lactose in casein,
- evaluation of the methods for the determination of egg-yolk in mayonnaise.

Support to the Services of the Commission

Various work was carried out by our specialists and laboratories in connection with measurement and materials characterization problems, chiefly for the purpose of preparing EEC directives:

- ***pesticide residues:*** optimization of a selective gas-chromatograph detector ; participation in the preparation of a guide-book for analysis of pesticide residues;
- ***fertilizers:*** in the ISO context, analysis of nitrogen (nitrate form) by different methods for different concentration ranges and under the influence of some parameters (ureic nitrogen, potassium salts); determination of phosphorus in aqueous and organic medium; evaluation of repeatability and reproducibility of nitrogen determination (ammonia); comparison of different methods for determining ureic nitrogen; reproducibility studies for potassium determination by gravimetry;
- ***surfactants:*** critical examination of the currently available methods for determining biodegradability;
- ***Pb and Cd release from glazed ceramic tableware:*** study of the feasibility of setting up a "hot test" or establishing a relationship between the cold and the hot tests;
- ***cosmetics:*** secretariat work in connection with the development of reference methods for specific problems;
- ***classification, labelling and packaging of dangerous substances and preparations:*** secretariat work and technical compilations; preparation of technical documents;
- ***nomenclature of the Common Customs Tariff:*** a provisional inventory (organic products) was printed in July 1974 (four single-language volumes – French, German, Italian and Norwegian), this inventory being updated constantly with new products.

Reference Materials and Chemical Analysis

This part of our work deals with the preparation of reference materials whose composition, impurity content and/or purity level had to be certified. Owing to the high level of accuracy needed, many different methods and numerous laboratories (indirect action) are involved and a great deal of development work is necessary.

Participation in Indirect Action

a) Non-ferrous materials

Our main efforts were devoted to:

- refining the analytical method for determining Sn in Sn-ore concentrate;
- preparing the certificates for three Zn ore concentrates ;
- determining trace impurities in electrolytic copper (S, Ni, Pb, Sb, Bi, Ag, Te, As);
- establishing the methodology for the preparation of special purity reagents (HCl, HNO_3,HF, $HClO_4$);
- determining oxygen and hydrogen in non-ferrous metals (W, Ni, Mo, Ti, Ti alloys, industrial Cu, Pb) by different methods;
- developing methods for N_2 analysis in W, Ta, Ti, unalloyed Ti and Zr;
- determining traces of noble metals (Pd, Pt) in Cu.

b) R.M. for Ferrous Materials

After the setting-up of a "European programme" concerning coke and coal powders, the Ispra laboratories measured the different parameters of interest (moisture, ash, carbon, hydrogen, nitrogen, sulphur, chlorine, phosphorus in ash), in different coke samples.

c) R.M. for Airborne Particulates

A preliminary analytical exercise, with the participation of 38 European and American laboratories, was initiated by the Division . As regards the JRC Ispra laboratories, nuclear activation, X-ray fluorescence, flame and flameless atomic absorption, emission spectroscopy, flame spectrometry, combustion techniques and wet chemical methods were employed for the determination of some 60 elements and compounds.

d) R.M. for Aquatic Plants and Sediments

300 kg (fresh weight) each of two aquatic plants were collected, dried, ground, sieved and homogenized. Preliminary homogeneity tests were performed by X-ray fluorescence, microcombustion and flame atomic absorption. The basic composition of these materials was determined.

Collaboration with the US National Bureau of Standards

Under this collaboration scheme, our work on the determination of different elements in bovine liver (Ca, Ag) and coal samples (Ca, Cs, Fe, Rb, Sc, Ta, Tb, Th, Zn, Ni, Cu, Mn, Cr, Pb, Hg, P) was completed, using various techniques. Extensive tests to ascertain the homogeneity of vegetable samples (citrus leaves, tomato leaves, pine needles, alfalfa) were carried out by nuclear activation analysis, X-ray fluorescence and flame atomic absorption spectroscopy on major and trace elements.

Reference Materials and Physical and Technological Properties

This activity includes the development of measuring methods, which should eventually become reference methods; at the same time the improvement of techniques and equipment and the preparation of calibration materials are all part of our programme. The field of physical and technological properties being very broad, only a few selected topics can at present be tackled by our laboratories.

The selected topics, which are all intimately interwoven with indirect action, are:

a) Toughness (charpy tests)

The work includes three phases:
- the calibration of Charpy test machines in order to get them up to DIN and, when appropriate, ASTM standards (this will be followed by a complete instrumentation of the machines);
- the full preparation of several hundred V-notch toughness samples for carrying out round-robin tests with, up to now, two national laboratories;
- participation in the round-robin tests with BAM (Berlin) and LNE in Paris;
- the JRC provides the technical secretariat and coordinates the action.

b) Tribology

Up to now the work has comprised two phases:
- the construction of a new type of tribometer, offering a number of advantages over existing ones. This tribometer is to be circulated amongst three national laboratories TNO, BAM, LIUT) for comparative tests;
- the preparation of a large number of friction couples, carried out in 18 varieties. These are to be distributed to the above-mentioned national laboratories for a round-robin test, with a view to evaluating the spread of results. The JRC provides the technical secretariat and coordinates the entire action.

c) Thermal Conductivity

Here our activity is centered on the comparison of two methods for measuring thermal conductivity in poorly conducting solids (insulating materials, glasses, fibre structures etc.), one being the classical hot-plate and guard-ring static method, which is standardized, and the other the much simpler and more elegant transient method, developed at JRC. A classical high-precision device to measure the thermal conductivity of liquids has been built and is ready for calibration and use.
The national laboratories participating in the work (round-robin tests) are LNE, ERDE (NPL), FIW and the University of Padua.

The JRC provides the secretariat and coordinates the entire action.

d) Newtonian Viscosity

The JRC work centred on two aspects:
- the setting up of a Couette absolute viscometer, which will allow of checking the various correction factors applied to relative measurements.
- the building of a device that makes it easy for us to supply data on viscosity at temperatures different from room temperature (there are requests from the petrol industry for such data on mineral oils).

Round robin-tests have already taken place and JRC is providing the technical secretariat and coordination. The institutes and laboratories involved are TNO, PTB, BAM, LNE, NPL, Labofina and Kon, Shell.

e) Ultrasonic Fault Detection and Standard Defects

The work is centered on two phases:

- the making of microdefects as detection standards for ultrasonic equipment, and studies on fabrication techniques, geometry and orientation of defects;
- the characterization of ultrasonic transducers and their backing equipment.

This second phase is a vast operation, since the number of parameters, both mechanical and electronic, is considerable. The definitions, parameters, techniques etc. are constantly discussed with a group of highly qualified experts, who participate actively in the indirect action. The JRC provides the secretariat and coordinates the entire action.

f) **The secretariat for many specialist groups and indirect-action projects** which have no JRC laboratory participation is provided by scientific staff of the JRC Ispra.

Protection of the Environment

F.Geiss

Introduction

This programme started in 1972 under a special contract between the elder six member countries and the Directorate General of the Joint Research Centre. Mutatis mutandis it continued essentially along the same lines in the years 1973 through 1975. During this period the in-house research ("direct action") was completed by an extra-mural research programme ("indirect action") covering some 150 shared-cost contracts in the following fields:

- epidemiological studies of the effects of air and water pollutants
- effects on health and on the environment of lead pollution
- effects on health of micropollutants
- evaluation of ecological effects of water pollution
- remote measurement of air pollution
- data bank on environmental chemicals (ECDIN).

Both parts of the programme are specifically directed towards supplying scientific support for the Action programme "Environment" of the Community (especially with regard to "reduction of pollution and nuisances"), published on the 20th December 1973 in the Official Bulletin of the European Communities. To ensure that the direct and indirect action (the latter conducted by the Directorate General XII, Research, Science and Education, Brussels) of the Community environmental research programme are coherent and complementary they are assisted by the same Advisory Committee for Programme Management (ACPM).

During 1974 and 1975 the direct action of the programme consisted of the following activities:

Actions 1974/1975	Manpower 1975 man/years	Budget 1975 (u.a.)
Analysis and measurement		
Multidetection unit	8.2	20,000
Data Bank ECDIN	75.6	58,200
Pathway and/or effects of pullutants		
Chemistry of air pollutants (4)	7.0	26,100
Pollutant uptake by plants and soils	4.25	9,700
Transfer of heavy metals in env. systems	10.65	38,500
Lead pollution by traffic	2.8	35,500
Biological water pollution tests	3.0	11,100
Biochemical effects of heavy metal pollution	2.6	14,100
Biotelemetry of effects on animals	5.5	32,500
Models, system studies		
Studies on eutrophication	9.0	35,700
Physical air pollution studies (5)	18.5	118,900
Environmental impact assessment	2.5	0,300
Other subjects		
Water purification/characterization of carbons	2.4	10,500
TOTAL	82.0	433,100

To the manpower of 82 manyears has to be added analytical and electronic support equalling another 15 manyears. The figures for manpower and operational budgets were basically the same in 1974.

Analysis and Measurement

Multidetection Unit (for analysis of organic micropollutants in environmental samples)

After the air sampling technique on Tenax columns a water sampling method on the same material with a recovery of 70-90% (at 20 ppb) has been developed. The introduction of the "heart cutting technique" gives better GC separation. On the computer side the development of the necessary software is almost achieved. The online connection with the 370 IBM computer is being prepared. The MS library comparison program was complemented on the 370. Link with ECDIN and in particular CROSSBOW is being prepared in order to obtain structural diagrams together with compound names.

First field measurements (fingerprint chromatograms) with air samples taken at different seasons show the impact of vegetation on com-

pounds present in the atmosphere. Preliminary experiments in HPLC were directed to high boiling fractions of water extracts. Emphasis has been placed on studies with polymer bonded stationary phases and improvement of the gradient elution.

Data Bank for Environmental Chemicals

ECDIN is now in a pilot phase collecting data on up to 5,000 chemical compounds. Earlier the project went through a stage in which a large number of discussions were held to ascertain what might be the needs of potential users. In order to give people an idea of the possibilities, some test data were put into a computer retrieval system and used for demonstration purposes.

The main activities during the current phase of the project are:

- decision on which data would be useful and hence would be included,
- collection of data for a maximum of 5,000 compounds,
- development of a "data format". For each element of data included, it is necessary to define what it is and how it should be written down,
- development and testing of a "format" for the exchange of data within ECDIN,
- input of data to the computer and adaption of the data to the computer retrieval system,
- implementation of a suite of computer programs (CROSSBOW) which performs various operations on chemical structures e.g. generation of structure diagrams, substructure search,
- computer systems development, especially in relation to the manipulation of chemical structures for chemical structure/biological activity prediction and for environmental pathways prediction,
- preliminary work to form links between a computer-based mass spectra research, chemical substructures search and the chemical data systems,
- evaluation of the data collected so far in terms of its ability to satisfy the needs of potential users.

At present data is being collected for the 5,000 compounds and during 1976 it should be possible to consult users on whether the data is satisfactory. It will only then be possible to give reasonable estimates of the data collection costs.

Pathway and/or Effects of Pollutants

Chemistry of Air Pollution

Tetraethyl lead (in air mixture) is decomposed by the UV part of sunlight with a half life of about 5 h on bright sunny summer days and of some 3 days under cloudy conditions or in winter. No decomposition at night. All decomposed lead went rapidly to the walls.

Some further experiments on the influence of the addition of water dissolved ions (HCl, H_2SO_4) on the particle charge have been carried out. This activity will now be suspended.

The following particle counters are now available: Climet, Jacobi particle counter, Witby particle counter, mobility spectrometer, condensation nuclei counter, 2 cascade impactors (low and high volume).

SO_2 Uptake by Plants and Soils

The phytotron with SO_2, CO_2 and moisture control is now operating. SO_2 is easily taken up by aereal parts of bean plants and transported to others.

Two pre-phytotron studies (leaf surface bioelectric reactions of ***Zinnia elegans*** under SO_2 fumigation and uptake of Pb, Cd, V by lichens and bryophytes) are in progress.

Green oak leaves collected from Mount Etna show higher S content on the windward side (2,200 against 1,700 ppm).

The experimental chamber for soil absorption is ready; the first results have been obtained.

Transfer of Heavy Metals in Environmental Systems

Lead transfer from air to water: Studies of particle size distribution vs. time were completed. It was found that the lead transfer to water was not effected by water surface conditions or water quality parameters. The chemical form of lead in water is under study by ultra-centrifugation.

The transfer of heavy metals in freshwater ecosystems: The objective is to evaluate the impact and hazards caused by heavy metals released into a lacustrine environment. Studies in progress concern the transfer of Cd and Zn from water and food to fish and the study of simple benthic food chains (water-organic sediment-insect larva-fish).

Transfer of heavy metals in irrigated cultures (rice): The objectives are to assess the influence of heavy metal pollution on the heavy metal content of rice and to assess the influence of irrigated cultures on the heavy metal content of soils. The study is being carried out at three levels: a) ***laboratory studies:*** soil-water equilibria. Absorption isotherms and kinetics are being performed for Cd and Pb. b) ***green house studies:*** rice cultures have been started with soils contaminated with 0-2-8-24 ppm Cd. Periodical sampling is already being carried out. c) ***field studies:*** material balance of

heavy metals in a typical rice farm (in cooperation with an indirect action). Field instruments were prepared and installed for periodical sampling.

Lead Pollution by Traffic (ILE Project)

In order to differentiate automative lead from other lead sources only lead of a particular and constant isotopic composition (206/207 = 1.04) will be sold in Italy for a two-years period. It differs significantly from the lead normally found in the environment in Italy (206/207 = 1.18 ± 0.02). This experiment started late in 1975. A total of 25,000 samples from gasoline, particulate matter, blood, vegetation, soil, and surface water will have to be analysed, principally, by mass spectrometry. The analytical precision of the MS determinations is now at 0.2% rel for 10^{-7} g of lead.

Biological Tests of Water Pollution

The objective of this research is the evaluation of short and long term effects of low concentrations (from 1 ppm to some ppb) of heavy metals (Hg, Cd, Cr, Cu, Ni, Pb) on freshwater organisms (algae and freshwater snails to be used as biological tests) and of the combined effects of these metals in association with detergents and chelating agents (NTA, EDTA, humic acids).

- A turbidostat has been tested: The flux of the culture medium is controlled by the same production-rate of the algal population and the amount of algae produced between two measurements is recovered and quantitatively estimated. The intensity of primary productivity can then be measured directly. Batch experiments have a lower sensitivity than those carried out in the turbidostat.
- Batch and continuous flow experiments on embryos and adults of two freshwater snails (*Biomphalaria glabrata* and *Lymnaea stagnalis*): This method has been standardized and can be used for any type of pollutant.
- A method has been standardized to record short-time effects (a few hours) produced by heavy metals on the heart-rate of *Biomphalaria glabrata*.

Biochemical Effects of Heavy Metal Pollution

In long term exposure experiments 50 ppb of ^{109} Cd labelled Cd^{2+} were daily administered to rats via drinking mineral water. Liver, kidney, G.I. tract and pancreas were found to be the only organs accumulating cadmium after three months' exposure. In all cases cadmium was bound to proteins with similar molecular weight (M.W. 10,000 - 11,000); no significant ^{109} Cd was present in other sub-cellular fractions (nuclei, mitochondria and microsomes). Preliminary experiments on Cd accumulation in rat liver CdBP (cadmium binding proteins) showed that single doses up to 1 mg Cd/kg b.w. induce a dose-proportional "de novo" synthesis of liver, whilst repeated doses cause a dose-proportional increase in CdBP synthesis yielding additive accumulation.

During the reporting period the following studies were completed:

- isolation, purification and characterization of rat liver and kidney metallothionein, a cadmium binding protein (CdBP)
- identification of Cd binding sites in rat testicles and spleen
- *in vivo* incorporation of radiotracers in rat liver CdBP
- *de novo* biosynthesis of rat liver CdBP. Effects of heavy metals on the biosynthesis itself.

New studies on lead and selenium exposure to rats were started recently.

Biotelemetry of Effects on Animals

An animal-mounted 4 channel transmitter was developed in thick film technology for further miniaturization (new concept). This transmitter is now being assembled. A receiver with automatic adjustment for long time recording was also constructed. The transmission chain was shown to work very satisfactorily over a period of 3 weeks without battery exchange. A new very high frequency transmitter is being designed in order to improve the animal-mounted antenna efficiency.

Capacitive electrodes have been developed for the detection of the heart beat of the laboratory animals. Later on they should also be able to detect the respiration data, with less artefacts from movements.

The very small localization circuits mounted on the legs of test animals and needed for the selection of populations within the total of laboratory animals under test during nerve reflex measurements have not yet been tolerated by the rats. Tests with young animals undergoing a phase of habituation are in progress and are promising. As a consequence, the development of the instrumentation for the heart beat rate recording has been brought forward since these measurements do not require the localisation of the animals as does the under-foot stimulation for the nerve reflex.

Models, System Studies

Eutrophication Studies

The objective of this study is the evaluation of the "ecological efficiency" of sewage treatment plants and the following of the trophic evolution of a large water body before and after the installa-

tion of the plant. The studies were mainly done on Lake Lugano. 23% of the total phosphorous load comes from run-off. If only this fraction of input were present, this lake would already be in a mesotrophic state. Therefore purification of sewage should be such as to reduce the other sources of phosphorous to 90%, to allow the lake to reach a mesotrophic level. This recovery is followed by a buoy measuring O_2, temperature, pH, redox potential and conductivity at six different depths. Three mathematical models were developed, to describe a) the seasonal evolution of phytoplankton in relation to light intensity; b) temperature gradients and their dynamics and c) to evaluate the turnover time of the water masses in the various basins.

Physical Air Pollution Studies

a) **Raman-Lidar:** The electronic hardware for this instrument has been completed and the Ruby laser equipped with a Q-switch. The instrument is being equipped with the dual wave-length absorption facility delivered by MBB (indirect action).

b) **Tunable IR laser, Barringer:** A study has been done to evaluate the effects of atmospheric turbulence on the laser beam propagation over a 800 m (1,400 m) optical path at 30 to 40 m above ground level in autumn, summer and winter under varying atmospheric conditions. The maximum beam deviation was 10 cm.
Three IR lasers are operating at 8.5 and 4.9μ, covering parts of the SO_2 and HN_3 absorption spectrum (recorded), with cell measurements. An assessment of the "derivative technique" is being made.
With a Cospec II B Barringer spectrometer and a 75 W Xe lamp we measured horizontally the mean SO_2 concentration over 1,000 m (10 ppt in a föhn situation, 40 ppt on a hazy day).
A feasibility study of a calibration cell for Lidar (consisting of 3 waggons moving on rails, 6 m total height of the train) was made, including detailed drawings and cost evaluation. The idea was abandoned because of excessive cost.
A variable path cell (10 to 100 cm) particularly suitable for calibration of correlation spectrometers was constructed.

c) **Meteorological measurements** (monostatic acoustic sounder, miniature radiosondes, ground-based meteorological instruments; in two mobile units)**:**
Measuring campaigns in Venice (together with CRN and ENEL). 2-weeks' operation near a power plant to study the situation when the stacks overtop inversion layers. Participation in studies of air turbulence and dynamics of inversion layers.

d) **Modelling** (elaboration of a basic concept of feasible "air quality management systems" for industrialized urban regions).
The stochastic simulation model has been successfully tested with fictitious input data. To overcome difficulties in adapting this model to practical situations, studies are being conducted on the use of tracers for the indirect determination of dispersion-relevant space-time, distributions of wind vectors, "absorption" coefficients and turbulent diffusion. The procedures for transfering measured tracer concentrations into air modelling input data are, as a concept, now ready in Ispra and are likely to be programmed by an external institute.
The statistical short-time prediction model has been tested with (practical Frankfurt) data, a corresponding "prediction catalogue" is in preparation.

Environmental Impact Assessment

a) A report on the **potential environmental impact of commercial navigation of Lago Maggiore** has been edited.

b) **The Pathway of Mercury:** A literature study concerning the pathway of mercury in Europe (air, water, soil) and a simple simulation model (system dynamics) allow the calculation of the time dependence of the average concentrations of mercury in air, soil and mud in Europe for the next 25 years. Some of the current parameters are: concentration of mercury in coal and oil, time constant for evaporation of mercury from soil etc.
In addition, computer runs are being done to examine the time-dependence of the mercury concentrations for different policy alternatives, e.g. increased recycling of mercury, a complete halt to mercury consumption etc. Similar studies on trace metals like Cd, Pb, Chr etc. will follow.

c) **The use of waste heat from electricity plants:** A literature review of waste heat applications was made. Two of the most important applications for waste heat at 30°C are fish cultures and greenhouses.
In fish nurseries a 2 to 3 times greater yield can be obtained by using waste heat from power plants. Not much heat is dissipated and the warm water coming out of the fishpond enriched with large quantities of organic waste from fish is a much heavier burden for the environment than cooling water alone.

Other Subjects

Water Purification by Catalytic Oxidation

Substantial progress was made: A series of screening tests was completed to determine the relative activity of different catalysts with the oxidant ozone (about 3 ppm) and model pollutant pyridine (weak absorption). The most efficient catalysts (with respect to reaction rate and low residual concentration of pyridine) are 0.5% Ag on Al_2O_3, CoO_3/MoO_3, 1% MuO_2 on Al_2O_3, 0.5% Pt on Al_2O_3, and some particular ± Al_2O_3. Process evaluation studies are in progress.

Remote Sensing of Earth Resources

S.Galli de Paratesi

Introduction

In 1973 a small programme on Remote Sensing of Earth Resources was approved by the Council of Ministers. The research programme, known as the AGRESTE Project, was prepared by the Joint Research Centre, Ispra, in collaboration with three of the Commission's Directorates-General in Brussels (for Agriculture, for Development and Cooperation and for Research, Science and Education), the Statistical Office in Luxembourg and some national institutes. The Project was conceived as a "renewable resources" investigation by remote sensing methods on some selected areas of European interest for agriculture (rice) and forestry (poplars, beeches and conifers), using the data of the NASA's Earth Resources Technology Satellite LANDSAT-II, launched early in 1975.

After a preliminary phase developed in 1973 to provide the co-investigators' staff with the indispensable remote-sensing background, the AGRESTE work concerning the Northern Italian test-sites proceeded in a two-phase approach:

- pre-launch preparation
- post-launch application (1975) and continuing investigation.

Pre-launch Preparation

As a consequence of the encouraging results obtained in 1973 the resources allocated to the objective were increased in 1974-75 and the JRC's preparatory activity was intensified, this effort being considered an indispensable premise for a successful post-launch operation.

The principal effort has been devoted to setting up methodologies in ground observation, airborne survey and data processing.

Of the four sectors of the AGRESTE investigation the following were considered:

irrigated crop: rice
artificial forest: poplars.

This priority was given considering the amount of resources allocated for this phase of research and by reasons of relative importance. Rice and poplars are, in fact, two significant "food-and-wood" subjects for Southern Europe. They are found together in one artificial ecosystem on test-site No. 1 (Po valley), the most suitable for a joint effort by the JRC-Ispra and the collaborating Institutes.

Some specific investigation items were considered taking into account the possibility of tackling them with the available technical means.

Correlating Reflectance with Biomass and Yield for Rice

First experimental field measurements campaign

The analysis of the 1973 preliminary measurements made on the Ispra lysimeters showed that a linear correlation should exist between the total overground biomass and mathematical combinations of reflectance values in LANDSAT channels (ratio $\rho 7/\rho 5$). In this experiment variations of biomass were obtained only by variations of fertilizer. The ground-test campaigns for 1974 were designed to separate the influence of parameters other than fertilizer, such as halm density and rice varieties. For this reason three different sets of experimental fields were considered:

a) seven fields at Vercelli where the same variety of rice has been cultivated at constant halm density and treated with different amounts of fertilizer;
b) ten fields at Valeggio where the same variety of rice has been cultivated with the same amount of fertilizer but starting from different plant density.
c) ten fields at Vercelli where as many different varieties of rice have been cultivated at constant halm density and treated with the same amount of fertilizer.

Canopy reflectance measurements were carried out weekly from July to October using an EXOTECH mod. 100 radiometer mounted on a specially equipped motor-van. A certain number of results were gained towards a better understanding of the phenomena, which is the basic premise for the establishment of suitable mathematical relationships.

As a conclusion it appeared from these results that it is difficult to obtain a direct evaluation of

standing biomass on common rice fields by means of vertical radiometric measurements only, taken in the four wide-range LANDSAT spectral bands. However, a combination of reflectances in satellite channels 7 and 5, plotted against time, is in any case a good indicator of the growth of rice plants throughout their life. This means that there is a basic possibility of describing plant growth by means of radiometric functions and, perhaps, of predicting the biomass amount through a differential time-dependent model.

Laboratory Spectral Signature Definition of Poplar Leaf

Spectral signature definition of poplar leaf surfaces is necessary for defining peculiar features which allow remote sensing of different varieties of plants. Measurements were performed in the range (0.37-0.80)μm using a Cary 14 spectrophotometer. By reference to poplar afforestations in Northern Italy we found that the ***salix alba*** leaf, very diffused in the Po valley, can be distinguished from the poplar leafs. There is some difficulty in distinguishing poplar from Robinia (false acacia) which is quite widespread in the Ticino valley.

Realisation of a LANDSAT 4-channel Field Radiometer

For radiometric measurement of landscape features of either fixed targets or ground strips surveyed by means of low-altitude flights, we used a single type of radiometer, the EXOTECH model 100. Owing to misalignment of the 4 channels of this instrument and to the need to monitor incoming sun radiation during field work, a 4-way optical waveguide radiometer which obviates the difficulties met in the pre-launch measurement programme has now been built at the Process Engineering Laboratory of the JRC, Ispra. By means of this radiometer it is possible to aim exactly the target being investigated for each channel. FOV of 0.2°, 1.0° and 50° are possible. The instrument is particularly suitable for small-target surveys. Aiming in this case is made easier by the view-finder design which clearly displays the area being investigated. The instrument found immediate application in the rice-field measurement campaigns.

Correcting Satellite Data for Atmospheric Effects

The problem of correcting LANDSAT satellite and MSS aircraft data for masking effects of atmosphere has been considered at the JRC since 1973. An experimental approach was adopted, which allows us to obtain the atmospheric parameters by means of some direct measurements on the ground.

Referring to the four LANDSAT optical bands we convert CCT radiance data from the satellite into reflectance data by measuring several atmospheric parameters, e.g. sun irradiance, sky radiance, atmospheric transmittance, etc.

The EXOTECH mod. 100 radiometer is the instrument used for this application. Measurements of sun radiance were performed at an altitude of about 2,700 m on the Swiss Alps. Most of the other parameter measurements were made at Ispra.

The data-correcting methodology, now completely set up, has a twofold advantage:

1) satellite data are expressed in the same scale as ground reflectance measurements;
2) the signatures of ground objects become independent of atmospheric conditions and sun position.

An error evaluation has also been performed. This estimate reveals that the accuracy of the reflectance values calculated from satellite data on the basis of ground measurements of atmospheric parameters is of the same order as the accuracy of ground reflectance measurements.

Software Preparation for Processing LANDSAT Data

Using LANDSAT-1 magnetic tapes we prepared the software indispensable for the forthcoming LANDSAT-2 investigation. We also did a certain amount of application work.

PSU-Package preparation and extension

At the end of 1973 we obtained a copy of the software developed by the Pennsylvania State University for the same computer and the same system as that in use at Ispra (IBM 370/165). This software basically consists of

a) routines reelaborating the NASA tapes in a form suitable for interpretation and successive elaboration (i.e. visualization of grey-map print-outs), computing multivariate statistical parameters
b) feature selection, data reduction and automatic classification programs optimizing the flow and dimension of LANDSAT's four channels.

Some programs in extensive use have completely been rewritten by the JRC in order to improve their efficiency and flexibility: NMAP, UMAP, RATIO. Two application programs have also been written:

- NMAPW: an extension of NMAP allowing imagery to be transformed freely within the colour space. It also produces optionally statistical data for chosen test areas, histograms for every channel and/or cluster images for all pairs of channels. These features are useful for correcting atmospheric parameters and for reducing shadows in mountainous areas.

• CLASSW: a classifier using the input cluster limits given for pairs of channels to assign the points into classes on a Boolean-type decision rule. In connection with NMAPW we employed it for a first classification of poplars, using a test-area with questionable statistics.

Implementation and development of other programs

• RHOMAP: This program was rewritten by the JRC in order to transform radiance data, given in form of count rates on the NASA tapes, into ground object reflectance. The spectral signature becomes less dependent on temporal illumination conditions as defined by sun position and optical transmittance of the atmosphere. Several modifications have been introduced to allow evaluation of the aerosol density in the lower part of the troposphere (below 5 km) from visual range.

• PATRAM, ATRAM: These codes were written by the JRC for the evaluation of the measured atmospheric parameters. PATRAM calculates the path radiance from al-mukantar measurements of sky radiance. ATRAM calculates the transmittance of the atmosphere from the measurements of sun irradiance at different sun zenith distances.

• IMAN: for processing images using spatial as well as spectral information, the program IMAN was written to allow level-slicing, mask generation and masking, image parameter calculation and setting, Fourier-transform and many arithmetic and logic operations on images.

• CLAPIX: a classifier, which assumes independent data in a maximum likelihood decision rule. It has been used to verify the spatial separation between rice classes.

Applications on LANDSAT-1 imagery

Rice and poplars: We investigated rice and poplars along the Po and Ticino valleys and in the rice zone between these two rivers. Only twoLANDSAT-1 satellite scenes were available, 7 of October 1972 and 10 May 1973. Both of them cover a relevant part of test site No. 1, mainly on the eastern-side. Most of the work was performed on the May scene. Parallel work was undertaken for the October scene, with greater difficulty because the general contrast of this scene is rather weak. Some encouraging results were obtained in rice classifications. Poplars (closed fields) were identified with about the same degree of success as in the May scene.

Land-use applied to the Province of Varese: From NMAP and UMAP (based on a texture scheme, able to map the uniformity zones and the contrast zones of a scene) seven categories were identified: town, two types of water (lake Maggiore, lake Varese), swamp, high and low vegetation and highly reflecting objects. From the data of 7 October elaborated by STATS a region of about 27x27 m^2 around lake Varese was classified.

Post-launch Investigation

After the LANDSAT's launch we devoted our research more particularly to the following specific AGRESTE objectives:

• Rice investigations: ground-truth acquisition; measurements for correlating reflectance with biomass; radiance behaviour investigation of diseased plants.

• Forest investigations: ground-truth acquisition concerning poplars, conifers, beeches.

• Aircraft and satellite data processing: atmopsheric correction data acquisition; implementation of an interactive software package.

Some systematic series of radiometric, photographic and conventional on-ground measurement were carried out on the test sites in correspondance of a certain number of sufficiently cloud-free LANDSAT-2 passages selected on a phenological basis. Helicopters and aircrafts were used as low-altitude remote-sensing platforms. An eleven-channel spectral scanner aircraft flight was made on 7 August over four areas of test-sites No. 1 and No. 2, controlled by the Institutes. Two flight altitudes were chosen corresponding to the different on-ground resolution for rice and poplars.

Rice Investigation

Ground truth acquisition

For the purpose of automatic classification we checked the ground, locating each rice-field on 1/6000 scale maps, derived from cadastral maps; these were photographed and we built up some mosaics of the relevant zones. For the province of Pavia a very careful survey was carried out on an area of 57,298 hectares out of an overall agricultural area of 218,646 hectares. We obtained supplementary information by examining the farm registers to determine the successive crops, in order to ascertain as far as possible the actual situation on the ground at the time when the LANDSAT passed over it.

In parallel with the EXOTECH measurements of atmospheric parameters, reflectance of rice fields on the Chiappona test-area was also measured from helicopters at the times of LANDSAT's overpasses. Radiance measurements for a fixed sequence of field points were taken. A field of view at 15° was used, corresponding to the satellite's resolution element on the ground (80x80 m). The reflectance will be compared with the reflectance calculated from the digit numbers on the ordered

NASA tapes by use of the measured atmospheric parameters. Agronomic and meteorological conventional truth-data were collected on the ground at the same time.

Correlating reflectance with biomass and yield

Rice reflectance measurements in greenhouse conditions: We performed winter reflectance measurements on rice pots in a greenhouse at Vercelli, to obtain spectro-reflectance data related in a continuous wavelength variation mode to phenological stages of rice. The purpose was to pinpoint the most significant radiometric rice features also for interpretation of the MSS aircraft flight data. An Optronics 740 spectro-radiometer (0.3÷1.05)μm was used. The technique employed renders the data independent of the spectrum of the lamps used as well as of the solar radiation absorption by the greenhouse glass. The recorded curves were digitalized and the resulting punched paper-tapes were fed into a computer program which completed the data processing. We followed the behaviour of rice reflectance during the greenhouse growing cycle of the plants and are now trying to find a correlation between N_2-fertilization contents and other biological parameters (e.g. vegetative stage, leaf area, water content, mean dry weight of leaves and grain production).

Second measurement campaign on lysimeters and open field: The conclusion deduced after the 1974 series prompted us to carry on the research for a rice-plant growth model in two different areas:

- on lysimeter cells, where data can be collected during stated periods at short intervals (few days), on exactly the same continually checked clusters of plants;
- in a real open field, where data concerning biomass distribution can be collected weekly at a significant number of points, in order to obtain a statistical description of the field variability.

These series were run from July to October 1975.

The data collected on the JRC's lysimeters by the Biology Division and in the open field at Vercelli concern the phenological stage, weight of wet and dried biomass, halm density, surface area of leaves from the insertion level, nitrogen content in the biomass, and reflectances in the four LANDSAT channels. On the JRC lysimeters two different varieties of rice have been cultivated at standard halm density in twenty cells and treated with different amounts of fertilizer. An EXOTECH model 100 radiometer vertically attached to a special travelling rotary crane was used. Continuous-band radiometric measurements were also performed with the Optronics 760 spectroradiometer during a certain period of the vegetative cycle. In the open field at Vercelli the rice has been cultivated at standard values both of density and amount of fertilizer. The measurements were each time performed on sixty field points. In this case both the EXOTECH model 100 and the 4-channel portable radiometer developed at the JRC were used. The instruments were carried through the fields by a specially-equipped tracked farm truck. This measurement series produced a total of about50,000 data, which will be processed and analysed in 1976.

Thermal behaviour investigation on a diseased-rice lysimeter

To obtain more complete information on the radiation behaviour of healthy and diseased rice investigated in the open field in 1973, an experiment was carried out in Summer 1975 on the JRC's lysimeters at Ispra. Some plants carrying infected aphids were planted in three lysimeter cells. A cherry-picker was used, carrying on board two photo-cameras together with an EXOTECH model 100 radiometer (day measurements) and an AGA thermovision model 750 heat-camera (day-and-night measurements). It was found that "yellowing" of rice is detectable in the 3-5μm wavelength region, with up to 2°C thermal difference between the infected zone and the surrounding plants. No appreciable contribution seems to be given by the purely reflective part of the spectrum. The results of previous 1973 experiments seem to be confirmed, with the addition of the possibility of day "fore-warning" of the progress of the disease. Again, the night-time measurements appear to contribute little of use.

Forest Investigation

Ground-truth acquisition

Poplar plantations: The following activities were carried out by the Institutes in collaboration with JRC:

1) A series of surveys related to a test area of about 90,000 hectares in the Po valley zone between the town of Chivasso and Pavia, which has been designed as land to be permanently under poplar. The results were supplied as IR aerophoto-generated maps, scale 1:50,000, on which the exact areas of poplar groves of various age were marked in colour. In the same zone a specially controlled test-area was selected and surveyed photographically on scale 1:18,000. The whole region was divided into the following classes: non-forest area, natural forest, man-made forest (poplars) and water divided into rivers and rice paddies.
2) We began a series of specific investigations on two regions of particular interest for the interpretation of the LANDSAT data. They are

directed towards finding the topographical extent on scale 1:25,000 of: a) a number of poplar groves in the Torre d'Isola (Pavia) region, comprising 25 hectares which were the object of specific JRC radiometric surveys; b) the whole area termed "wooded" in the Partecipanza di Trino, which constitutes one of the largest forested areas of the Po plain (about 500 hectares). In this region poplar plantations are distributed among the natural forest, the natural composition of which was also indicated on the final maps.

Beech forests: Since 1973 the Istituto Nazionale Piante da Legno, AGRESTE co-investigator, has been carrying on a systematic inventory on a 150,000 hectares zone of test-site No. 3. The investigated zone is situated between 600 and 2,000 metres altitude. Beech-woods are the most widespread forestal class. A "point" inventory technique particularly suited for uneven ground areas is being set up; the method consists in fixing on a 1:25,000 scale map a set of sampling points corresponding to a square-meshed grid whose expanse depends on the requested inventory accuracy. A 25-hectare (500x500 m) grid element was chosen. The grid points are also transferred onto some other geologic and/or vegetation maps and aerophoto-generated mosaics. The characteristics of each projected point (i.e. its environmental conditions) are interpreted and digitally codified. The 1975 work progressed along the above investigation lines. The entire test-area has by now been aero-photographed (panchromatic and IR-colour) and is being systematically investigated by stereoscope.

Conifer afforestations: A complete ground-truth aerial photographic survey was made in October on the conifer afforestation of Dormelletto close to lake Maggiore. This area (19 km length) was also flown over by the MSS aircraft flight of 7 August. A set of two Hasselblad (IR-colour and N-colour) was mounted on a helicopter flying at 1000 m altitude.

Satellite Data Processing and Interpretation

Comparison of classification algorithms. Atmospheric correction data acquisition

On the basis of the Northern Italian imagery (70 mm transparencies) received from NASA in 1975, we ordered the corresponding digital tapes which are expected in early 1976. We made a first visual examination of the LANDSAT photo-imagery and in collaboration with the Istituto Geofisica della Litosfera did a comparison with the corresponding scenes for ERST-1.

In the meantime the activity on satellite data processing and interpretation has made progress as far as acquisition and processing of atmospheric correction data and development of new utility programs and of an interactive video system are concerned. We did some classification work for digital mapping and average estimates of poplar and rice of the 1973 LANDSAT scenes. The results of different classification algorithms were compared with the ground-truth mosaic data. A systematic series of on-ground measurement of atmospheric parameters for several ssatellite passages over test-site No. 1 (rice, poplars) was carried out. The measurements were performed at the farm "La Chiappona" near Mortara, where the staff of the ENR have some controlled fields. They indicate that the masking effect of the atmosphere varied considerably from one day to another and that it is not negligible. These measurements provide experimental data which enables us to eliminate the atmospheric masking effect from digital LANDSAT data prior to user's interpretation.

Implementation of an interactive software package

After a period of practice with the software for data processing, mapping and several sophisticated classification procedures, we found its most important drawback appeared to be the consumption of much machine-time and analysts' time. We therefore decided to develop an interactive system, compatible with the structure of the existing batch programs, which would permit a much faster and more flexible analysis of Remote Sensing data.

The interactive system being developed takes into account certain limitations imposed by the teleprocessing at present operative at the JRC. These restrictions plus the requested flexibility towards future installation of more sophisticated terminals made modular programming imperative.

The first programs developed up to now take care of the construction of subsets on disk-units, the maintenance of library files, the display of contents of disks and other book-keeping tasks.

A second group of programs developed consists of service routines commonly used by all interactive programs. A third group of programs is characterized by the fact that they are independent of terminal input/output. The functions are: mathematical operations, data-checking. The last group of routines are the conversational programs themselves. They consist of a logical series of questions, they accept the responses of the user, test their validity and distribute the required actions.

The operational programs developed up to now can perform construction of histograms, calculation of simple statistics, group-maps, automatic generation of level-slicing schemes and some organizational operations. The introduction of real statistical data extraction, cluster analysis and simple and sophisticated classification programs can be expected soon.

New Technologies Raw Materials Recycling

C. Rinaldini

The activity on raw material recycling was concentrated in 1974 and 1975 on prospective studies, discontinuing for the time being the exploratory experimental work carried out in the preceding year. This was due to the small total effort available, as shown in the following table:

Action	Budget (u.a.)	Manpower (man/years)
System analysis studies	3,000	2.5

Introduction

Recycling of raw materials may be valuable not only because of the economic benefit for the industries concerned, but also because it can slow down the depletion of resources and lessen pollution.

System analysis studies yielded some quantitative findings on the three foregoing points, in respect of a few specific materials chosen from the field of non-ferrous metals. The materials considered were: lead, tin, aluminium, chromium, copper and zinc. For each of these the sectorial consumption trends were simulated and, where appropriate, various degrees of recycling and of substitution were considered. The consequences to the economic balance, to conservation of resources and to the energy balance were assessed.

The Approach to the Problem

It has been shown recently that, with an exponential growth of consumption at its present rate, the reserves available at today's extraction cost will, as to some materials, last only for a short period of time.

A number of courses of action can be envisaged to improve this situation:

1. To use resources obtainable at a higher extraction cost. The reserves are increased by a factor of 10 in many cases if an extraction cost higher by 50% is considered.
2. To replace gradually, in some specific applications, the material of interest with other more abundant materials. The consumption growth rate will then be slower.
3. To extend the lifetime of the goods, therefore reducing the need to replace them. In this case, too, the consumption growth curve will be flattened.
4. To increase the recycled fraction of the used material, therefore using less resources while satisfying the same demand.
5. To reduce the material employed in the fabrication of each article, through skilful design and construction.
6. To reduce the quantity of goods produced. This presupposes a reduced demand due to a lower population level, a lower standard of living or a change in the values of society.

Courses 1 and 4 increase the reserves. Courses 2, 3, 5 and 6 decrease the demand. Course 1 will solve the problem of scarcity of resources in most of the cases and for a long period of time. Actually it is the main solution to such scarcity, but it goes in the wrong direction for the energy balance, the economic balance (in particular the balance of payments) and the pollution problems. This course in any case will not be followed, under free market conditions, until the next four courses have been tried up to the point where they entail costs higher than those required by the new raw material resources.

The other courses will all be undertaken at the same time, in different degrees, on the basis of cost and of sectoral and even casual choices.

Individually, apart from the first one, only the second and to some extent the sixth course can solve the entire problem. Recycling (course 4) alone or together with course 3 (extended lifetime) in most cases cannot substantially improve the problem of scarcity; nevertheless recycling coupled with a fair degree of substitution may considerably extend the lifetime of the reserves, especially when the demand growth rate is low. As far as the energy balance is concerned, course 1 usually worsens the situation because of the use of poorer raw materials; course 2 can improve the energy balance, depending on the kind of substitute used; course 3, 5 and 6 are energy-saving; course 4 has a potential

for improving the energy balance and often allows substantial savings.

As to pollution, courses 3, 4, 5 and 6 are effective in reducing the amount of waste, but only course 4 can, in theory, eliminate it completely. Course 2 sometimes improves, sometime worsens the problem and course 1 worsens it, as said before, and may do so dramatically.

Main Results

A very simple mathematical model was employed for the various analyses. The DYNAMO language was used to write a simulation model. The results so far obtained concern two kinds of calculation: the first refers to a parametric study of the influence of the extraction cost/recycling cost ratio on the depletion of reserves of an unspecified typical material; the second refers to an analysis of resources depletion as a function of various degrees of recycling and substitution for six specific non-ferrous materials (lead, tin, aluminium, chromium, copper, zinc). Where relevant, the energy-balance variation has also been calculated.

The purpose of the parametric study was to see what levels of recycling cost would be justified in order to delay the final depletion of resources. An ideal material was chosen and the relevant parameters were varied in a range typical of some non-ferrous materials. It was seen that, on the basis of a discounted balance over 20 years, taking the static index of the reserves as 10 and assuming a 50% increase of the extraction cost after depletion of reserves, recycling is economically attractive where recycling costs exceed the extraction cost by not more than 20%. For a discounted balance made over 50 years, the economic upper limit for recycling is at a recycling cost 26% higher than the extraction cost; for a static index of 30, the economic upper limit for recycling is at a cost 7% higher than the extraction cost.

The conclusion is that the purely economic incentive will stimulate recycling only when exhaustion of resources is quite near (20 or 10 years ahead).

For the analysis concerning the six non-ferrous materials reference was made to the European Community figures; where only world-wide data were available they were used for the Community by dividing them by a best-guess factor. The future trend of demand for the materials considered was assumed to follow the available forecasts, found in the literature, over a time range of 30 years. The trend was not analysed more closely, the main purpose of the work being to see the importance of recycling and substitution in any reasonable scenario, which could in principle be parametrically varied.

It was seen that for lead recycling increases by more than 50% the time for which the reserves will last; on the other hand no sizable improvement was found for tin, copper and zinc owing to the low feasible degree of recycling. For aluminium, recycling increases the quantity remaining after 30 years by a factor of about 2, and for chromium by more than 30%.

The possibilities of substitution were also investigated: no important easing of depletion is obtained by substitution for lead, tin, copper and zinc; but it is valuable for aluminium (more than 80% increase in the residual reserves) and very effective for chromium where the residual reserves after 30 years are increased by a factor of 6.

When recycling and substitution are introduced at the same time, aluminium improves yet further: the residual reserves after 30 years will increase by a factor of more than 2.

More intensive recycling, up to full recycling, was considered last. In this case the lead situation will be much better as, after 30 years, 50% of the present reserves will still be available. Even better is the situation regarding aluminium and chromium, with almost 90% of the reserves left. Tin was not included in this calculation as a high degree of recycling cannot be reasonably assumed.

The energy needed to produce the various materials under the various conditions of recycling was calculated for lead and aluminium. It was seen that as to lead an important energy saving is obtained already with recycling at the present rate; further increase of recycling will not improve the situation very much. As to aluminium, it was found that the various degrees of recycling would have a notable effect on the energy balance; with full recycling there would be practically no increase in the annual energy requirement over a period of 30 years, even with aluminium consumption rising at a rate of 5.9%/year.

New Technologies Solar Energy

J.Gretz

In 1973 the Council of Ministers decided upon a four-year direct-action programme on new technologies, namely, the use of solar energy and recycling of raw materials. The total budget for this objective for 4 years is 3.05 million u.a. The following table shows the effort (primary expenses and manpower) on Solar Energy:

Action	Manpower (man/years)		Primary expenses (u.a.)	
	1974	1975	1974	1975
Habitat	3.7	5	26,000	35,000
Materials	2.4	2.7	19,000	20,000
Photovoltaic	2	3	21,000	23,500
Photoelectro-chemistry and quantum conversion	3	3.5	25,000	20,000
TOTAL	~11	~14	91,000	98,000

Habitat : Applications of Solar Energy in Housing

In 1974 and 1975 our work on applications of solar energy in housing consisted primary in setting up test facilities for the determination of thermal performances of solar collectors and developing measurement procedures; studies of high-efficiency collectors; and preparation of a test facility for the study of combined heating, cooling and storage with solar energy.

Installations for Solar Collectors/Performance Testing

Three installations were built. The first consists of four water loops and one glycol loop for temperatures above 100°C. On this installation five collectors can be tested simultaneously. The second installation, on which one or two collectors can be tested, has a special mechanical device which allows for manual tracking of the sun.

The third installation is a solar simulator in which collectors of 1x2 m^2 can be tested with fluxes up to 1.4 kW/m^2. Measurements consist essentially in the determination of temperature differences between inlet and outlet of collectors, and of the mass flow of the transfer fluid. Insolation levels are measured with SOLAREX solar cells and a thermoelectric SOLARIMETER. Mathematical models based on a semi-statistical approach were used for the treatment and interpretation of experimental results. These facilities are not only used for the JRC programme but have also provided support for industry interested to acquire experience in testing in this field.

Development of High Efficiency Collectors

Conventional back-painted one-glass collectors have an efficiency of about 50% at working temperatures of 50°C with an insolation of 800 W/m^2. At working temperatures of the order of 100°C or at low insolation levels, the efficiency of these types of collectors becomes very poor. High-efficiency collectors are collectors which aim at an efficiency of 50% at working temperatures of 100°C. They are of particular interest for cooling applications with absorption cycles. Performances of solar collectors can essentially be improved by reduction of heat losses due to radiation and natural convection.

Different types of solution were investigated: selective surfaces, FRANCIA or honeycomb structures, partial vacuum, and corrugated geometries. Results showed that these types of collector are of interest only with high temperatures ($\cong$ 100°C). At temperatures below 50°C the increased cost is not offset by sufficiently enhanced performances. A report on the subject has been prepared and is available. Future activity should concentrate on long-term reliability and reduction of the cost of these different types of solution.

These activities were carried out in collaboration with outside organizations, institutes and industry (Prof. Francia, University of Genoa, Centre d'Etudes Nucléaires de Grenoble, ALUMETAL, etc).

Study of Combined Heating, Cooling and Storage Systems

The study of complete systems in which the solar collector represents only a component is essential for technological and economical evalua-

tions. The study of whole systems involving heating, cooling and storage will be carried out on a flexible test facility where components and subsystems can easily be changed. The construction of this installation is starting. Its main characteristics are:

- space for heating or cooling: 500 m^3
- 70 m^2 of solar collectors on a wall, facing south
- 100 m^2 of solar collectors on the roof with variable orientations
- 50 m^3 available for storage studies.

A lithium bromide absorption system has been purchased for cooling studies in connection with high efficiency collectors.

Materials: Preparation of Selective Deposits

The development of selective surfaces prepared by chemical and galvanic techniques was continued during 1975. The exploratory results obtained in 1974 indicated clearly that excellent reflectances could be obtained in the thermal radiation range for several industrial metal bases like copper, aluminium and steel. But absorption measurements in the visible range (which became operative in 1975) showed very clearly that much of the advantage of the reduced thermal emission was offset by reduced absorption in the visible range. Much of the work of this year was devoted to improving the absorption of selective surfaces in the visible range. Two methods were explored: 1) destructive interference by the development of double layers on a copper base; 2) development of a specular selective surface on stainless steel for use on a corrugated collector (directional selectivity).

Double Layers on Copper Base

The double-layers concept was considered for the following reasons. Simmple one-layer selective surfaces are based on the principle that a semiconductor behaves as a conductor for light in the solar radiation range, while it behaves as a dielectric in the thermal radiation range. Unfortunately most semiconductors have a high refraction index and this results in considerable Fresnel losses, this is the physical reason for the strong reduction of the absorption coefficient in the solar energy range.

The situation can, in principle at least, be improved by the deposition of a thin layer of appropriate thickness and optical constants, such as to produce destructive interference at the maximum of the solar spectrum. The optical constants of the galvanic layers were not at our disposal and no method for measuring was available at the time. So we tried empirically several combinations of CuO and nickel-black; deposition times for both semi-conductors were varied over wide ranges. An effort was made to measure the optical constants for both semiconductors by ellipsometric methods in order to relate quantitatively the absorption characteristics of the selective surface to the basic physical parameters of the semiconductors; the following values were found for CuO ÷ n= 1.5 and K = 0.2. Measurements on nickel-black have not been reproducible up to now and our research effort next year will be applied in this direction.

Nickel-Black on Stainless Steel

Stainless steel is an ideal material for the construction of solar energy collectors from the standpoint of durability, corrosion resistance to the working fluid, workability etc. For these reasons we tried to develop a selective surface for use in conjunction with corrugated collectors; the corrugation offsets the reduced absorptance in the solar energy range of this simple selective surface, but has the drawback of increasing the emissivity in the range. The opening angle of the corrugation can be optimized as a function of the optical properties of the surface. Typical results obtained are reproducible and could be applied for industrial application.

Exploratory Work on Paints and Varnishes, Miscellaneous

Exploratory work was continued in the field of varnishes. The first problem was to find transparent resins for thermal radiation. Several resins were tested for infrared transparency; the best values were about 60% in the thermal region for acceptable film thicknesses. The best of these resins were charged with a special charge which was absorbent in the visible range and reflectant in the IR range. Some reflectivity was obtained, which proves that the theoretical scheme for a reflective paint is valid.

Measurements

The specular and diffuse measurement attachments to the Cary spectrophotometer were installed and tested during the year. The instrument is operative for determination of the absorptance in the visible region of the spectrum.

Total Spherical Emittance for Thermal Radiation

An experimental device was constructed during this year for the measurement of the total hemispherical emissivity. It was based on the well-known relation

$$M = \epsilon^{\circ} (T_4 - T_4)$$

The determination of ϵ involves precise measure-

ment of M, T_1 and T_2. The results on some standard materials are in good agreement with results obtained by NBS (USA) and PTB (Germany).

Photovoltaics: Photoelectric Conversion of Concentrated Solar Radiation

The primary task of photoelectric energy conversion research is to cut down the cost per produced energy unit. Since the chief obstacle to economic utilization of solar energy lies in the low incident energy density, this could be done in two ways:

1) by the development of low cost solar cells, and/or
2) by concentration of the incident radiation.

The latter case will still remain valid even if great progress were made in the former. On the other hand it may well be that by the first approach alone it will not be possible to reach the ultimate goal of competitive large-scale energy costs. Various discussions have shown that the necessary low cost for the converter material lies at the limit of technological feasibility. Moreover, it is not enough to lower the costs by increasing the market volume, since this would require too large an amount of public money to subsidize that market. In the end, therefore, the concentration concept may really offer the only viable approach to a final large-scale use of solar electricity.

Concerning the converter concentrator approach we performed a cost analysis which shows the following, in regard to three cases which differ in the cost of available solar cells:

- cells at 2000 \$/m² for applications between 0.5 and 5 kW,
- cells at 500 \$/m² for applications between 5 and 100 kW,
- cells at 100 \$/m² for applications above 100 kW.

For the first case, simple low-concentration devices will allow a cost reduction to about 40 c/kWh; this is a level at which autonomous diesel aggregates are used. High concentration could lower the cost eventually to 5 c/kWh, i.e. to the level of residential electricity costs, but the optical system would probably be too expensive to meet this goal.

In the second case, medium concentration could lower costs to 5 c/kWh, if suitable inexpensive concentration systems could be found. Finally, for the third case, medium concentration could lower costs to about 1 c/kWh and even low-concentration devices could still have a substantial impact since large investments would be made at that stage, thus making any minor savings economically attractive.

On the basis of this analysis we set up an experimental programme in order to perform a series of proof-of-concept experiments. Any converter/concentrator system confronts us with two kinds of problem:

- Converter problems: The use of standard solar cells at high concentration results in inefficient conversion, which is due to the decrease of conversion efficiency with increasing temperature and to the increase of internal losses caused by the finite series resistance of solar cells. Both these effects were only of minor importance in space problems and therefore viable and inexpensive solutions do not yet exist, but they are feasible.
- Concentrator problems: Since for the former problem solutions can be found by specialized laboratories (e.g. within the Indirect Actions Programme) we directed our efforts towards the concentrator part of the system. The general problem for energy concentrators is twofold: one has not only to find good effective concentration ratios but at the same time to optimize the collection time in view of the apparent solar motion.

Within the scope of our actual programme we are mainly interested in two classes of concentrators:

1. stationaty or quasi-stationary linear collectors for optimum low energy concentration (of immediate but also of very long-term interest),
2. linear concentrators with 1-axis rotation (of medium-term interest and essential during the economic break-through phase of solar electricity).

So far we have been collecting data from the following systems:

- a V-trough concentrator,
- a parabolic trough concentrator,
- a compound parabolic trough concentrator,
- a linear Fresnel lens concentrator,
- a standard Fresnel lens concentrator.

The first four are linear quasi-stationary systems, the last one is a 2-axis system for comparison purposes. Alongside each of the five systems there is a reference converter without concentration. For the final assessment of the potential of the concentration concept, incident radiation will also have to be taken into account. For that purpose we have installed various radiation instruments for permanent monitoring of total and diffuse radiation falling on a horizontal surface. Another value registered is the radiation to a surface which is kept normal to the sun rays (total and direct component) by means of a heliostat. In addition, the spectral distribution of incident light can be obtained in fixed or tracking mode.

Since one purpose of this study is the long-term collection of data for concentrator systems under environmental conditions, we have to handle a relatively large quantity of data. For this reason

we have developed a special low-cost multiple input coding interface which allows storage of all measurements on a small computer.

Concerning first results we have seen that the amount of diffuse radiation at our experimental site is too high to use a simple trough collector with real advantage: effective energy gain factors are below 1.5 in the long-term average. For higher concentration ratios one should use at least a compound parabolic concentrator, although this has the disadvantage of needing curved mirror surfaces and a relatively large reflector area. From our present preliminary results we conclude that the Fresnel system offers probably the most promising solution (eventually after addition of a second stage concentrator for improvement of the collection time).

The emphasis in executing the present study during the last year of the multiannual programme will be mainly on

- a critical evaluation of obtained data,
- an investigation of 1-axis rotating devices and finally on
- a cost benefit analysis based on various operational systems.

It is also hoped to include in the final assessment an estimate of the impact of new cell developments, such as high-intensity silicon cells with and without conductive transparent electrodes, vertical junction cells, and perhaps also GaAs or CdTe cells.

Photoelectrochemistry and Quantum Conversion

Study and Development of Electrochemical Solar Cells

A photovoltaic effect can be observed everywhere at interfaces in which an internal electric field causes a separation of charge carriers; this is the case at semiconductor p-n junctions, at semiconductor metal interfaces (Schottky barrier) and also at semiconductor electrolyte interfaces. So far only photo-cells and solar cells based on the first two types of junction have been developed for technical use, whereas there has been no effort to develop photoelectrochemical cells based on the last type of junction. The reason lies mainly in the fact that electrochemical cells have a higher weight factor than solid-state cells and therefore did not win financial and technical support in the various space programmes.

Nevertheless photoelectrochemical cells may offer some advantages which could lead to substantially lowered production costs:

- no p-n junction,
- a good prospect of using polycrystalline semiconductors (Gerischer)
- no contacting problems
- possible use of the cell as a hybrid system with the electrolyte as the natural transfer medium.

The aim of this research is to contribute to a fundamental study and to the technical development of electrochemical solar cells. The study opened with an investigation of the working principle of the TiO_2/0.1 m Na_2SO_4/Pt type of cell. TiO_2 is a semiconductor with a band gap energy of 3.04 eV corresponding to a light absorption edge of about 4100 Å. In spite of this low absorption edge, the study of this semiconductor indicates that it is chemically very stable and delivers at sufficiently high light intensities a photo potential greater than the water decomposition potential.

The following results were found: under illumination with unconcentrated sunlight the cell works self-regeneratively, converting solar radiation into electrical energy only. At the TiO_2 electrode oxygen is evolved according to the reaction $p^+ H_2O \longrightarrow 0.5\ O_2 + 2H^+$ (p^+ being a hole generated together with an electron by illumination), whereas at the cathode the same amount of oxygen is consumed in the reaction $0.5\ O_2 + 2H^+ + 2e \longrightarrow H_2O$. At light intensities corresponding to a concentration of 500 suns, however, the cathodic reaction might be the hydrogen evolution $2H^+ + 2e \longrightarrow H_2$. Then the overall process would be photocatalytic water decomposition. Owing to the high concentration necessary for such a process it is more economic to work the cell as a direct light/electrical energy converter and to produce hydrogen conventionally in an electrolytic cell.

Chemical Storage of Solar Energy

In the field of chemical storage of Solar Energy a study was undertaken concerning the possibility of transforming solar radiation in its natural diluted form (i.e. without concentration devices) into chemical energy (fuels). The thermodynamic limits for the conversion of solar energy into other energy forms, in particular into chemical energy, were established. These general energy considerations were then applied to the natural photo-synthetic system. General criteria for artificial photochemical systems suitable for the storage of solar energy were formulated and some of the current proposals for their practical realization were discussed. In a published report on the subject the author expressed doubt concerning the feasibility of a single-phase photochemicalenergy storage system, believing rather that the combination of photoelectric and electrochemical systems might will be the best way to an efficient chemical storage of solar energy.

Fissile Material Control

M. Bresesti

The 1974-75 activity of the Joint Research Centre in the field of R&D for fissile material control was essentially a continuation of the work carried out in the previous years. The Joint Research Centre has been active in this field since 1969 with the main objective of giving scientific and technical support to the Safeguards Directorate of the Commission and with the further aim of providing methods for more efficient fuel management in the nuclear industry.

Support has been given to the Safeguards Directorate in different fields: system analysis, destructive and non-destructive techniques, sealing and identification techniques, and the training of inspectors.

The activity of the Joint Research Centre is coordinated with similar work carried out in national organizations, within the framework of the European Safeguards Research and Development Association (ESARDA) which now comprises AEK (Denmark), CEN/SCK (Belgium), CNEN (Italy), EURATOM, GfK (Germany), RCN (Netherlands) and UKAEA (United Kingdom). The secretariat of the Association is held by Ispra.
Apart from this, direct collaboration in special fields has been established between JRC and industrial firms.

The JRC Fissile Material Control Programme is mainly carried out at Ispra with limited participation by the Transuranium Institute, Karlsruhe, but there are, in the framework of other programmes, a number of activities going on at Karlsruhe and Geel which are also of considerable interest for fissile material control.

The main areas of work during 1974-75 were the following:

- System Analysis
- Isotope Correlations
- Non-Destructive Assay of Fissile Isotopes
- Destructive Assay of Fissile Isotopes
- Sealing and Identification.

During 1974 a four-week training course, reserved for the inspectors of the Safeguards Directorate, was organized at Luxembourg and Ispra.

During 1975 a two-week course in Safeguards and Fissile Material Control for safeguards inspectors, plant operators and governmental officers was organized at Ispra. These courses are described under the heading "Training and Education Programme".

On March 1974 the Symposium on the Practical Aspects of R&D in the Field of Safeguards was held in Rome under the sponsorship of ESARDA. The Ispra staff ran the scientific secretariat and presented three review papers.

A breakdown of the budget (excluding personnel charges) and of the manpower (first line people) allocated for the different actions of the programme is given in the following table:

Action	Manpower (man/years)		Budget (u.a.)	
	1974	1975	1974	1975
System analysis	1	1.5	2,000	1,000
Isotope correlations	1.5	2	–	–
Non-destructive assay of fissile isotopes	9	9	85,000	110,000
Destructive assay of fissile isotopes	2.5	3	40,000	35,000
Sealing and Identification	5	5.5	35,000	35,000
TOTAL	19.0	21.0	162,000	181,000

System Analysis

The system studies, which are directed towards the development of safeguards systems for nuclear plants, are generally carried out in close collaboration with the Euratom Safeguards Directorate. This activity was strongly increased at the end of 1974 with a view to the coming into force of the Non-Proliferation Treaty.

The entry into force of the Treaty will signify the application of rules which have been established, in fairly broad terms only, in the Verification Agreement between Euratom and IAEA, but which will have to be implemented through much more detailed procedures laid down for individual installations. For the actual implementation of the Agreement, there is a need for a series of studies, some new, some already in progress, and for the production of procedure manuals, sampling techniques, statistical testing, etc. for use by the

inspection staff in the field.

The contribution of the JRC was particularly important for the definition of control systems in nuclear reactors of different types (MTR, LWR, FBR).

In connection with work on the definition of control systems in reprocessing plants it is worth mentioning the experiment, concerning the reprocessing of MTR fuel elements, which is being conducted in collaboration with CNEN on the EUREX reprocessing plant. The main objectives of the experiment are the verification of the fissile material balance declared by the operator, the collection of information on MUF and the study of isotope correlations.

Isotope Correlations

Isotope correlations are an extremely useful tool for checking plutonium in the input of reprocessing plants. In the JRC both experimental and theoretical work has been carried out. In addition a data bank of isotopic compostions in irradiated fuels has been established at Ispra.

Experimental Work

Results concerning heavy-isotope and fission-product correlations were produced in the post irradiation analyses of uranium fuels (LWR) and plutonium fuels (FBR and plutonium recycle in LWR). The analyses were carried out at the Karlsruhe and Ispra Establishments.

Under a collaboration agreement with ENEL (Italy) a new gamma-scanning experiment was carried out during 1974 on the spent fuel assemblies discharged from the Trino Vercellese reactor after the 3rd irradiation cycle. The aim of the work was to investigate the possibility of correlating information gathered through gamma spectrometry measurements with data on burnup and plutonium content obtained from nuclear code calculations and from chemical analysis. 16 fuel assemblies, irradiated at a burnup level of between 20,000 and 28,000 MWD/MTU, have been measured in the pond of the Trino Vercellese reactor. The relations between ^{137}Cs activity and burnup and between ^{134}Cs/^{137}Cs activity ratio and plutonium content, observed in previous experiments carried out on fuel assemblies of the Trino Vercellese (2nd core) and Garigliano reactors, were confirmed.

Theoretical Work

A theoretical analysis of the correlations between heavy isotopes and fission products ratios in LWR's fuels was carried out. The dependence of the correlations on fuel enrichment and moderation ratio was studied. The following isotopic ratios were considered:

$$\frac{^{134}Cs}{^{137}Cs} \quad \frac{^{154}Eu}{^{137}Cs} ; \frac{^{84}Kr}{^{86}Kr} , \frac{^{86}Kr}{^{83}Kr} , \frac{^{84}Kr}{^{83}Kr} ;$$

$$\frac{^{132}Xe}{^{131}Xe} , \frac{^{134}Xe}{^{131}Xe} , \frac{^{132}Xe}{^{134}Xe}$$

$$\frac{^{146}Nd}{^{145}Nd} , \frac{^{146}Nd}{^{148}Nd} , \frac{^{148}Nd}{^{145}Nd} .$$

Part of the results of this study are described by C. Foggi et al. in their contribution "Isotopic Correlations Based on Fission Product Nuclides in LWR Irradiated Fuels".

During 1974-75, sensitivity studies were carried out for 104 fission products to study the influence of the cross-sections upon their concentration in irradiated fuels. The errors in the fission-product concentrations arising from the uncertainties in the neutron cross-section were evaluated analytically; it was generally possible to define simple analytical expressions allowing the calculations of these errors. The analytical expressions were checked with the ISOTEX-1 code.

Two reports were published during 1974 describing the ISOTEX and the improved ISOTEX-1 codes which are utilized for the calculation of heavy-isotope and fission-product concentrations in irradiated fuels.

Data Bank of Isotope Correlations

For the purpose of developing the isotope correlation techniques with a view to their applications for safeguards, fuel management and physics calculations, it was decided, in accordance with the decision of the Steering Committee of ESARDA, to create at Ispra a Data Bank which will collect the available data on isotopic compositions and fission products in irradiated fuels. These data are obtained either from post-irradiation experiments or from reprocessing-plant input analyses. The work is carried out in collaboration with the Karlsruhe Establishment.

Collection of the data is in progress. The data bank software which is developed in collaboration with RCN, Petten, is composed of three sub-programs which will make the following operations possible:

- calculation of the correlations by means of the ISOTEX code on the basis of the irradiation data
- Data retrieval and statistical treatment
- Plotting of calculated and experimental data.

Collaboration has also been established with the IAEA in the field of data bank preparation.

Non-Destructive Assay of Fissile Isotopes

In many cases, for instance in that of finished fuel elements and heterogeneous materials only non-destructive measurements allow the determination of fissile material content. In other cases non-destructive methods are largely superior to destructive ones, because of their rapidity or the ease of transport of the relevant equipment. Thus the application of these techniques is to-day a necessary condition for implementing an efficient and economic control system, and may on the other hand help the operators of nuclear plants to improve their own measurement basis for fuel management.

The work on the development and practical application of neutron and gamma techniques was continued in collaboration with the Safeguards Directorate and nuclear plants.

Neutron Techniques

In the field of neutron techniques an important experiment was carried out at the NUKEM plant on the use of a photoneutron interrogation device (PHONID) for the assay of non-uniform and bulky uranium-bearing samples.
On the basis of the results of the experiment the device was redesigned during 1975 and the first part is already in construction in the JRC workshop. This prototype will be purchased by the Safeguards Directorate.
Being a versatile bulk fuel assay device, it will be capable of measuring the fissile content (U, Pu) of samples varying in size up to 50 litres and ranging from a few tenths of a gram to several kg of fissile materials.
The source neutrons are produced by an isotopic source (Sb-Be) and their spectrum can be readily adjusted by means of filters (hardening, softening). The detection system is based on He 4 recoil detectors.

Other action to be mentioned concerned the installation of the SIGMA apparatus at the HOBEG plant and the continuation of the study on the spontaneous fission neutron measurements. The SIGMA apparatus, fabricated in 1973, was put into operation during 1974 for checking AVR and THTR fuel pebbles. The apparatus is based on neutron irradiation of the fuel pebbles by Cf252 sources and detection of the delayed neutrons emitted after the U235 fission.

The studies carried out in the previous years on spontaneous fission neutron measurements found during 1974-75 a large field of application for plutonium waste monitoring in the framework of the Nuclear Waste programme.

Gamma Spectrometry Techniques

The experiments carried out on spent fuel assemblies are reported under the heading "Isotope Correlations".

In the field of gamma spectrometry it is worth mentioning the CALGANE experiment which was carried out during 1975 at the BELGONUCLEAIRE plant under a collaboration contract with CEN, Mol, and BELGONUCLEAIRE.
In this experiment gamma spectrometry techniques were combined with neutron and calorimetric techniques in the measurement of different types of plutonium fuel pins (KNK, BR3, Venus).

Considerable work was carried out during 1974-75 for the preparation and automation of gamma spectrometry lines. Mechanical parts were designed and fabricated for the scanning of fuel pins and fuel samples having a cylindrical geometry.
For the automation of the gamma scanner two systems were designed and fabricated according to the CAMAC standard; the first is based on the use of a LABEN 70 computer, the second on the use of a specially developed microprocessor.
The first system was fully tested during 1975.

During 1974 two portable multichannel analysers for gamma spectrometry measurements were fabricated and delivered to the Safeguards Directorate.

Preparation of Reference Samples

In order to calibrate instruments to be used for non-destructive assay, the preparation of reference samples with a known content of fissile materials is required.

A set of AVR and THTR fuel pebbles with known U235 content were prepared by means of non-destructive intercalibration with neutron and gamma techniques, followed by chemical analysis. These reference pebbles are being utilised for the calibration of the SIGMA apparatus at the HOBEG plant.

In collaboration with NUKEM work has begun on the preparation of a set of U/Al cermet cores to be used as reference samples.

Calorimetric, passive neutron and gamma ray measurements were performed on special production fuel pins of the type KNK and BR3. The characterisation of these samples is to be completed in 1976.

Destructive Assay of Fissile Isotopes

Three main activities have been carried out at Ispra in this field: development of sampling techniques, development of mass spectrometry and participation in interlaboratory comparisons.

Sampling Techniques

Under a collaboration contract with NUKEM an apparatus for UF_6 sampling was fabricated. On the basis of the tests carried out in the NUKEM plant, a new version of the apparatus was designed. Two prototypes will be fabricated for the Safeguards Directorate.

A new version of a previously developed powder sampling apparatus has been constructed.

Mass Spectrometry

The possibility of uranium analysis by an easily transportable mass spectrometer was investigated. A quadrupole mass spectrometer was considered suitable to meet the requirements. The work will continue during 1976.

Interlaboratory Comparison

Ispra partecipated in the GAE programme, which is an interlaboratory comparison organized by the New Brunswick Laboratory involving determination of the isotopic and chemical composition of UF_6 samples.

In the context of the IDA-72 experiment organized by GfK, Ispra participated in an alpha-spectra evaluation test.

Sealing and Identification

Through the use of sealing and identification techniques the inspection effort in safeguards operations can be reduced considerably

The techniques, used at Ispra for tamper-resistant sealing and identification, are based on the ultrasonic detection of randomly distributed inclusions in different materials.
The 1974-75 activity comprised:

- Sealing of MTR Fuel Assemblies
- Sealing of LWR Fuel Assemblies
- Sealing of FBR Assemblies
- Development of Portable Apparatus for the Identification of Seals

Sealing of MTR Fuel Assemblies

In the light of the good results obtained during 1973 in the irradiation of sealed fuel assemblies (rivet seals) in the HFR reactor at Petten, the Safeguards Directorate decided to start large-scale application of the seals on MTR fuel assemblies.
Seals were put on all the fuel assemblies of the HFR (Petten) and BR2 (Mol) fabricated during 1974 and 1975.
During 1975 the first seals were put on the fuel assemblies fabricated by CNEN (Saluggia). During 1976 the application of seals will be extended to German reactors.

Several problems connected with the sealing and identification of MTR fuel assemblies have been solved. Tools have been developed for the extraction of seals in the ponds of reactors and reprocessing plants. A modification of the identification method makes it possible now to identify the seal in the pond without removing it from the fuel assembly.

Sealing of LWR Fuel Assemblies

Four sealed fuel assemblies (cap seals) have been under irradiation since 1973 in the Gundremmingen BWR. Two sealed fuel assemblies have been under irradiation since 1972 in the Lingen BWR.

A procedure for checking the fuel assemblies of the STADE PWR was studied, based on the sealing of the foot of the fuel assembly and on the identification of the upper grid.

Remote-control devices were fabricated in order to read in the reactor pond the identity of the cap seals fixed on the BWR fuel assemblies and the identity artificially introduced into the upper grid of the PWR fuel assemblies.

Sealing of FBR Fuel Assemblies

For the identification of the fuel bundle a marked disc can be put in the thick part of the nozzle and the identity can be checked by means of an automatic device in the inspection cell of the reactor.
This identification method was extensively studied at Ispra during 1975, for the fuel assemblies of the KALKAR reactor with the collaboration of the firms responsible for the fuel design (BELGONUCLEAIRE and INTERATOM).

Portable Apparatus for the Identification of Seals

During 1974 the first portable apparatus, a miniaturized ultrasonic identification system contained in a small suitcase, was completed and delivered to the IAEA.
During 1975 a new version of the instrument, with a higher degree of automation, was designed.
Two prototypes are now in construction and will be delivered in 1976 to the Safeguards Directorate and the IAEA.

Part 2

THE SCIENTIFIC DEPARTMENTS

Introduction to Department A

Informatics, System Analysis and Information

H. J. Helms

The Department A is mainly composed of the former CETIS (Centre Européen de Traitement de l'Information Scientifique) Division, and relevant components of the former Nuclear Studies Division. Its activities encompass informatics, application of informatics, mathematics and systems analysis, as well as activities in the information and documentation fields. The disciplinary competences of the staff are available to a substantial number of the JRC research objectives and to a certain extent to the Commission services. Furthermore, a few of the Department's activities have the character of public services. The Department also includes in-house service activities such as the central library with the text service, and the large JRC Computing Centre installation.

The period covered by this report has in general been characterized by a need to adapt to changing circumstances in the form of new demands both from the research objectives and from the clients of the more service-oriented activities. To cope with these demands there has to be a continuous process of consolidation of the skills of the available human resources, of building up competences, and of establishing an adequate framework within which to operate. This process is not yet complete, and will in any case be continuous.

Excellent progress can be reported so far, with the staff accelerating new areas of activity. Credit must certainly be given to all members of the staff for their enthusiastic involvement, both in activities established at an earlier stage, and in the newer areas, and particularly in those cases where demands have exceeded the resources – a situation which is not unfamiliar to this Department. As always in the past, results are documented in scientific journals, Euratom reports, presentations to scientific meetings, and in reports prepared for the Advisory Committees for Programme Management. Members of the Department have, however, also had the pleasure of an increasing number of scientific visitors who, over shorter or longer periods, have contributed to professional discussions and have helped to build up contacts with colleagues in national institutions, universities and industry. Moreover, the highly appreciated scheme of stipends has provided an opportunity to work together with young scientists pursuing their advanced studies here. This has constituted a healthy challenge to our own knowledge and abilities.

The following paragraphs are a survey of some of the activities carried out during the two-years under report, up to the end of 1975.

Informatics

The JRC Computing Centre provides a global computing service covering all JRC scientific/technical activities, the administration, and Infrastructure services. It also serves the NEA Computer Program Library located on the premises of the Establishment, certain Commission services in Brussels and, to a limited extent, a few outside users (mainly those with whom the JRC already enjoys some form of collaboration). To meet all these demands, a user-oriented advisory and consultancy service has been amplified and reshaped, and will remain an area for further developments. Although the Centre has been equipped since 1972 with an IBM 370/165 system there have only been limited configuration developments. Those implemented so far have increased the disc storage space to cater for the needs of the data banks, and have also developed the terminal park. In 1975 plans were made, however, for short term developments aimed at a more balanced configuration in 1976. This envolved acquisitions from several different firms. The systems support staff has continued to improve the basic software, thus ensuring highly reliable operations. The workload, which increases by about 20% per year has made it necessary to introduce two full shift operations in 1975, as compared to the former arrangement of one shift extended in over-time. While many have contributed to the achievements of the Computing Centre, special acknowledgement is due to the operating staff, in particular because there have been difficult negotiations at Council level for a shift-work remuneration scheme which only partly meets the proposal made.

In the field of basic informatics systems work also continues for the COST-11 action, European Informatics Network. We are participating in the management of the project, in the complex

technical work of defining the features of the network and in the preparations for installation of the computer as a nodal centre. This should occur in early 1976. Under this project the staff will not only exploit its own scientific-technical competences, but will also participate in a truly European collaborational effort involving not only the other nodal centres, but also colleagues from several other institutions belonging to the countries contributing to this action. In late 1975 one staff member was made available to the Executive Body of the action on a one-year basis.

The longstanding competences developed in the fields of software adaptation, program portability and efficient software sharing and software transfer are being exploited not only for the benefit of the Establishment, but also, in particular, for the action EUROCOPI (European Computer Program Institute) which forms part of the objective Applied Informatics. The operation of this flourishing public service activity encourages continuing research into the underlying skills, increasing contacts with similar groups in the member countries, which are about to become more formalized, and has led to further development of a database management system (SIMAS) now in use in other Ispra data banks as well as a modular program system. Service requirements and developments go forward steadily, hand in hand, thus ensuring an adequate level of competence.

Informatics Applications

The Informatics support to administrative problems furnishes technical support in the administrative data processing field to the JRC and, upon request, the Commission services. The activities range from problem analysis to production of the computerized results, and also include pilot experiments. The main achievements to be reported are the completion of the system for the management of the functional budget by objectives (CORIG), which has demanded a great effort on the part of the staff concerned and has now reached the stage of regular and reliable production with an important series of new facilities and improvements. Another significant result is the implementation of the Personal Data Base. This, amongst other things, has made possible the setting up of an on-line inquiry procedure on the Personnel File-using terminals.

Several new procedures and programs have been developed for the automatic telephone invoicing procedure, the workshop procedures etc. A pilot experiment to summon staff members to periodical medical checks is also in progress.

Work has been done outside Ispra for the JRC Geel Establishment and several Directorates General in Brussels, including DG V, DG VI, DG IX, and DG XII, and has involved the running of statistical programs, implementation of library systems and consultative work.

During the period under report there has been occasion to perform interesting studies and challenging experiments in advanced software techniques in response to client requirements.

In order to ensure contacts with the Commission data processing activities the Director of the Department has taken part, when necessary, in the meetings of the Management Committee for the Commissions Computing Centre in Luxembourg.

In Information Science the major efforts have been towards an integrated system of automatic documentation with software developments for a generalized system of language processing and automatic indexing. The work carried out in the objective Applied Informatics also involved close contact with the Directorate General for Scientific and Technical Information and Information Management (D.G. XIII). To this end there is also regular participation in the meetings of the Committee for Information and Documentation in Science and Technology (CIDST), and its Technical Aspects group. In addition Methodological support and assistance has been provided for the data bank development at Ispra. Emphasis is being increased, both on this activity, and on collaboration with the EURONET project (DG XIII).

The mathematicians have developed methods in mathematical models, numerical methods, stochastic processes, Bayesian techniques and classification methods which are being applied in several

research objectives and also in studies on computer systems' performance evaluation. The great need for applications of mathematics has also led to course activity in statistics and to collaboration with national statistics institutes, in particular the Institut de Statistique, Paris, including several seminars and visits.

Involvement in the research objectives on Remote Sensing of Earth Resources has led to the successful building up of competences and software to treat and exploit satellite data by graphical methods, and, while the equipment possibilities are still rather limited, firm plans are being made to build up a complete laboratory for image processing and accurate data interpretation. Such a facility will go a long way towards fulfilling the long-felt need of graphics developments for several present and future research objectives.

As far as mathematical methods for physics and engineering are concerned, modelling methods and numerical techniques are being further developed for theoretical reactor-accident analysis.

Substantial work is being performed on the Lagrangian code REXCO-H and on the Eulerian code SURBOUM. A research activity to obtain a more adequate constitutive law for water has been started.

Comparison between code results (REXCO-H, ASTARTE, ARES, SURBOUM), and small scale model experiments is systematically being performed with the aim to validate codes in the context of an European program, COVA.

The results obtained have led to periodical contacts and to meetings for discussions with experts in national establishments. The first results on code evaluation have already been published.

ESIS – INDAC

The ESIS-INDAC staff are concentrating on the highly specialized scientific area of radiation physics, and on computational physics.

A number of advanced shielding codes have been assessed, technical consultation is expanding and information dissemination has become current practice; the quarterly ESIS-Newsletter provides a worldwide perspective of shielding events and the Shielding Data Bank has proved to be a valuable information retrieval tool. Due to the closure of the ISPRA-I reactor, a new improved shielding irradiation facility was built at the TRIGA reactor of the University of Pavia.

The accuracy of radiation transport methods is improving and there is a corresponding escalation in data requirements, both as to quality and quantity. As a result of this situation the INDAC activities have shifted towards the retrieval, processing and evaluation of nuclear data for shielding applications. Data requirements are also intimately connected with the sensitivity methods developed; these studies provide a rational guide for defining priorities in measurements and evaluations of cross-sections.

System Analysis

The work of the Division has concentrated upon the analysis and computer modelling of physical and technological systems, including technico-economic aspects.

The main part of the activity during 1974 and 1975 has been devoted to the analysis of technical and engineering systems and contributions in this field have been made to the various programme objectives.

In particular, extensive efforts have been made on safety analysis, by performing a study of the evolution of major accidents in nuclear reactor power plants: Light Water Reactors (LWR), High Temperature Gas-cooled Reactors (HTR) and Liquid Metal Fast Breeder Reactors (LMFBR) were considered. For LWR's, besides the improvement of the series of computer programs COSTANZA for the calculation of reactor core transients, a special effort has been made in the field of analysis of the blowdown accident. Existing computer programs have been implemented, tested and used for sensitivity studies and a new approach to the analysis of the accident has been proposed; the related model has been programmed for the computer (NICKY computer program).

HTR's safety studies concerned the adaptation of COSTANZA programs for the specific core

geometries of this reactor type and the extension to the study of the water gas accident. For the latter purpose the coupling of COSTANZA with the English program TUBER made possible an analysis of the behaviour of the whole neutron-thermohydraulic system under accident conditions. The investigation of the whole core accident for LMFBR's has led us to perform an assessment of the various approaches of the national laboratories of the EuropeanCommunities to the analysis of this accident. Further work is in progress to arrive at a common understanding of the physical phenomena and, later on, to establish a common calculation method.

System analysis of various reactor types for Safeguards purposes was continued and further improvements of isotopic correlation techniques as a tool for the control system have been achieved, covering not only the heavy isotopes but also a selection of stable and unstable fission products.

Some of the calculation methods developed for Safeguard studies were adapted to the analysis of the radioactive waste disposal problem: new calculation tools were also acquired and assessment studies performed on the technical-economic feasibility of disposing of actinides by recycling them in nuclear reactors.

A model of the hydrogen production system by thermochemical water splitting was studied and programmed for the computer.

In support of the activities of the General Directorates for Energy and for Industry, a number of studies of the electrical energy system of the Community were performed, covering the analysis of various alternative policies for the installation and use of conventional and nuclear power plants. For the latter, LWR, HTR and LMFBR were considered and the implications for primary energy sources, industrial infrastructure and costs were studied.

Analysis of the sea transport system was performed for two main purposes: to assess the role of nuclear merchant ships in future European fleets and to evaluate the consequences of recent events on the shipbuilding industry. The problem of scarcity of mineral resources was tackled by a model study of the importance of recycling for a selection of non-ferrous metals.

On the subject of systems analysis, work on a dynamic model for simulating future EC energy demand and supply on a very long-term basis should also be mentioned.

Library, Text Service

The central library, which is available to the Establishment and also to some outside users had at end of the report period an inventory of 51,000 books and more than 200,000 reports. In 1975 there were around 1300 subscriptions to journals and holdings of some 25,000 journals volumes. The library, which also provides a documentation service, counted in 1975 almost 15,000 visitors, 2500 telephone consultations and 4500 loans.

1975 saw the organisation of a new text service which involved the unification of the publication office whose tasks are to register the Ispra publications and ensures liaison with DG XIII, and document preparation, composition, reproduction and a photographic laboratory. The new service, which also includes a much appreciated translation and manuscript revision service, has proved to be a very valuable instrument in meeting the ever-increasing demands, and in particular has given great assistance with various papers and reports, prepared often at very brief notice, in connection with the planning of the JRC Future Programme.

Isotopic Correlations Based on Fission Product Nuclides in LWR Irradiated Fuels. A Theoretical Evaluation

C. Foggi, F. Frenquellucci, G. Perdisa

Introduction

"Isotopic correlation technique" is that branch of reactor physics which investigates the relationships (commonly termed correlations) between accumulation and depletion of the different isotopes in nuclear fuels subjected to irradiation. The isotopes which are taken into account are those of the heavy elements (U, Pu) and those of the fission product elements.

Correlations are mainly used as a tool for the prediction and verification of the fissile content in irradiated fuels. The consistency of isotopic analyses performed at the reprocessing plant can also be verified by use of the correlation technique [1].

Isotopic correlations are generally divided into three main classes, depending upon the isotopes which are taken into consideration:

- **Heavy Isotope Correlations:** only isotopes of the heavy elements (mainly U and Pu) are considered in this class: one of the terms of the correlations may be the burn-up of the fuel.
- **Stable Fission Product Correlations:** one term of the correlation is based on stable isotopes of fission-product elements; the other term is based on isotopes of the heavy elements or sometimes the fuel burn-up.
- **Radioactive Fission Product Correlations:** one term of the correlation is based on isotopes of the heavy elements (or sometimes the fuel burn-up); the other term is based on radioactive isotopes of fission products.

The three classes of correlations exhibit marked differences in respect of:

- their present state of development
- the techniques applicable for experimental determination
- their field of application
- their dependence upon the reactor characteristics and power history.

Correlations are the subject of both theoretical and experimental investigation [1]. Theoretical investigation is generally carried out by performing accurate burn-up calculations, from which correlations are derived. Experimental investigation is based on detailed measurement of irradiated fuel isotopic composition, from which correlations are derived [8,9,10,12].

This paper describes the theoretical investigations which are being carried out at the System Analysis Division, on the correlations based on fission-product nuclides. Some results are reported.

Choice of Fission Products

The radioactive fission products which can be considered for correlations are few in number. The nuclides which are retained must exhibit the following characteristics:

- reasonable long half-life (at least 2 years) allowing the recording of the whole power history of the reactor
- reasonably large fission yield (at least some tenths of one percent) so that the nuclide will be produced in sufficient amounts
- well defined γ-lines, at energies greater than 100 keV, with reasonably large branching value to allow easy and accurate measurement.

On careful analysis of all radioactive fission products, we found that only three nuclides are suitable for establishing correlations in LWR fuels, namely,: ^{134}Cs (half-life 2.1 y), ^{137}Cs (half-life 30 y), ^{154}Eu (half-life 8.5 y).

On the other hand, stable fission products which can be considered for correlations are numerous. Experimentalists have, up to now, confined their attention to the isotopes of Kr, Xe and Nd only. The reasons for this choice are:

- Kr and Xe are gaseous and so may be easily separated from the bulk of the irradiated fuel and analysed in a mass spectrometer.
- Nd is routinely separated from the bulk of the fuel, since ^{148}Nd is commonly used as a burn-up indicator: the Nd is therefore easily available for analysis in a mass spectrometer.

The isotopes which we retained for correlations are: ^{83}Kr, ^{84}Kr, ^{86}Kr; ^{131}Xe, ^{132}Xe, ^{134}Xe; ^{145}Nd, ^{146}Nd, ^{148}Nd.

Choice of the Terms of the Correlations

A correlation shows the relationship between two quantities. In our analysis the first of these two quantities is the fuel burn-up (expressed as the fraction of initially-present heavy atoms which have been burnt). The second quantity to be used in the correlation is based on the concentration ratio of two fission-product nuclides. The choice of a concentration ratio instead of an absolute concentration is dictated by considerations of ease and accuracy of measurement. In order to produce correlations which represent straight-line relationships, this second quantity must be an increasing function of the fuel burn-up; this requirement imposes a limitation on the number of quantities that can

be taken into consideration. After analysing all possible ratios, we retained the following:

$$\frac{^{134}Cs}{^{137}Cs} \qquad \frac{^{154}Eu}{^{137}Cs}$$

$$\frac{^{84}Kr}{^{86}Kr}\ ,\quad \frac{^{86}Kr}{^{83}Kr}\ ,\quad \frac{^{84}Kr}{^{83}Kr}$$

$$\frac{^{132}Xe}{^{131}Xe}\ ,\quad \frac{^{134}Xe}{^{131}Xe}\ ,\quad \frac{^{132}Xe}{^{134}Xe}$$

$$\frac{^{146}Nd}{^{145}Nd}\ ,\quad \frac{^{146}Nd}{^{148}Nd}\ ,\quad \frac{^{148}Nd}{^{145}Nd}$$

Calculation Procedure

The decay chains which include the fission product nuclides considered in our analysis are shown in Figs. 1 and 2. The calculation of the concentrations of the various nuclides was performed with the point burn-up codes ISOTEX1 [2]; the resulting correlations were compared with the experimental results by means of the code ISOCORR [3]. The nuclear data used in the calculations are taken from the following sources:

- fission yields, decay constants, branching ratios: values reported by Sola [2]
- cross-sections: average values calculated with the GGC-II code [4], or derived from the Westcott thermal cross-sections and the resonance integral reported in Ref. 11.

As is well known, some of the nuclear data found in the

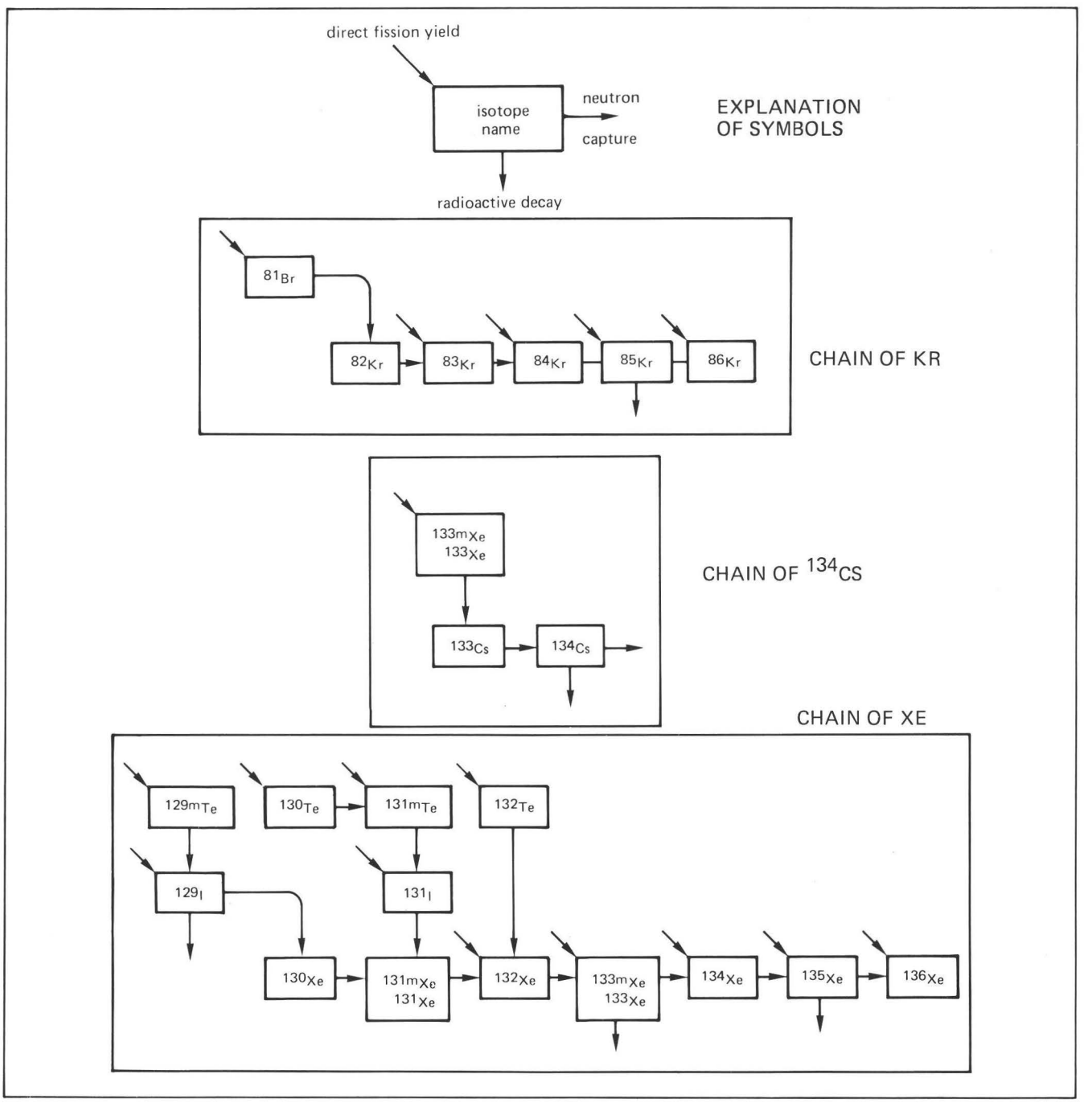
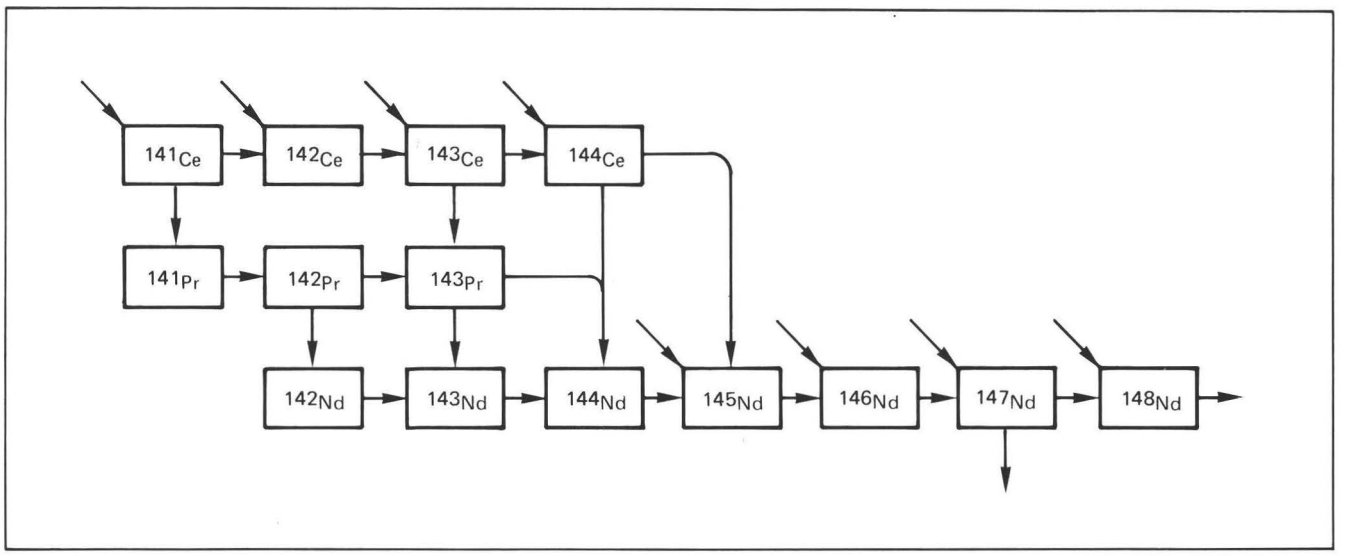


Fig. 1

CHAIN OF ND



CHAIN OF ^{154}EU

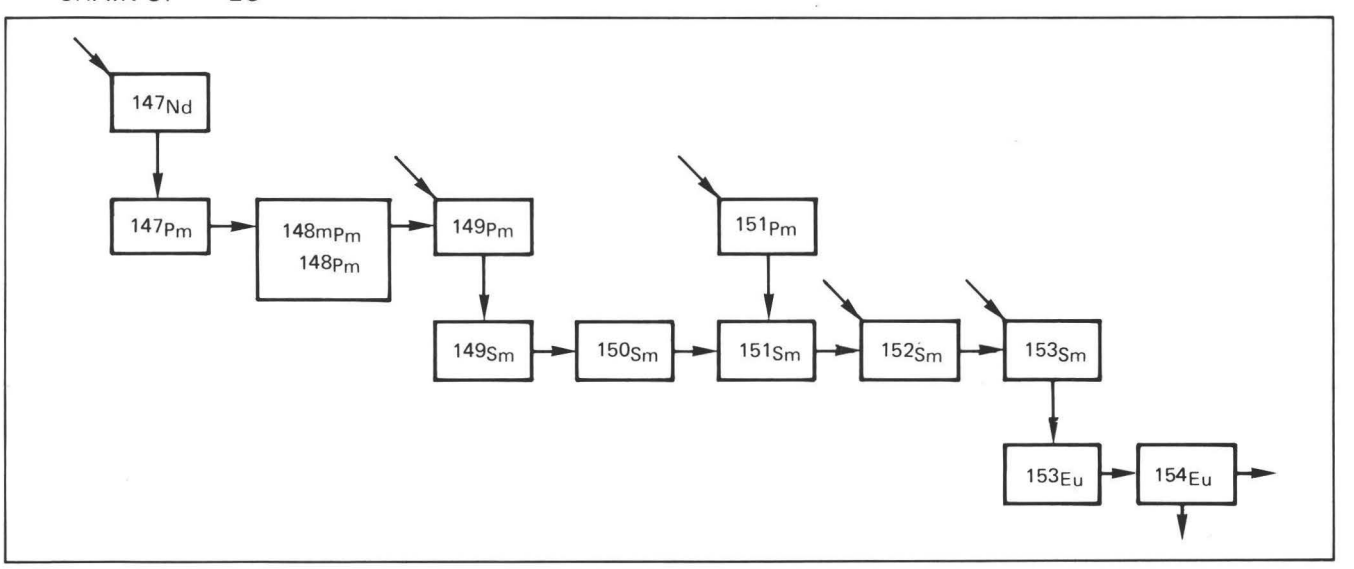


Fig. 2

literature are not accurate enough for an accurate calculation to be made. The inaccuracy of fission yields is in general not very large; the same holds for the decay constants, with the sole exception (as far as we are aware) of ^{154}Eu, whose half-life was quoted as 16 y [5] but is more likely to have the value 8.5 y [6,7]. The main sources of error in the calculation are the average cross-sections. This is so for two reasons: the values of the cross-section as a function of energy may not be known to sufficient accuracy and the neutron spectrum used in the averaging procedure may not have been evaluated accurately enough. Fortunately, not all the cross-sections which appear in the decay chains play an important role in the calculation. A careful analysis showed that only the following cross-sections are important (and must therefore be known with good accuracy):

- for calculation of Kr isotopes concentration: cross-section of ^{83}Kr
- for calculation of Xe isotopes concentration: cross-sections of ^{129}I, ^{131}Xe, ^{135}Xe
- for calculation of Nd isotopes concentration: cross-sections of ^{141}Pr, ^{143}Nd, ^{145}Nd, ^{147}Nd
- for calculation of Cs isotopes concentration: cross-sections of ^{133}Cs and ^{134}Cs
- for calculation of ^{154}Eu concentration: cross-sections of ^{150}Sm, ^{151}Sm, ^{152}Sm, ^{153}Eu, ^{154}Eu.

Parametric Analysis

With the codes and the procedures described in the preceding section, a parametric survey was performed. Only PWR fuels were considered (UO_2 type, zircalloy cladding), with enrichments ranging from 2 w/o to 4 w/o, and moderator-to-fuel volume ratios between 1.2 and 2.2. A total of nine cases were analysed.

The various correlations obtained are presented in Figs. 3-16. The parameter F_T represents the fraction of initial heavy atoms which have been burnt (and is roughly propor-

tional to burn-up). The label on each curve shows the fuel enrichment (w/o) and the moderator-to-fuel volume ratio to which the curve refers.

Figs. 3 to 6 show correlations based on Kr isotopes; Figs. 7-10 show correlations based on Xe isotopes; Figs. 11 to 14 show correlations based on Nd isotopes; Fig. 15 shows the $^{134}Cs/^{137}Cs$ correlation. Fig. 16 shows the $^{154}Eu/^{137}Cs$ correlation.

As can be seen, there is a marked dependence of the correlations on fuel enrichment and moderator-to-fuel volume ratio. In the case of the $^{134}Cs/^{137}Cs$ correlation, there is also a strong dependence on the fuel power history; this effect is now being analysed. It must be remarked that one consequence of this dependence is that the correlation for a single fuel pellet is substantially different from the correlation for complete fuel batches.

Comparison with experimental results from Trino Vercellese [8,12], Garigliano [9] and VAK [10] reactor fuels was satisfactory, with some minor corrections to a few nuclear data.

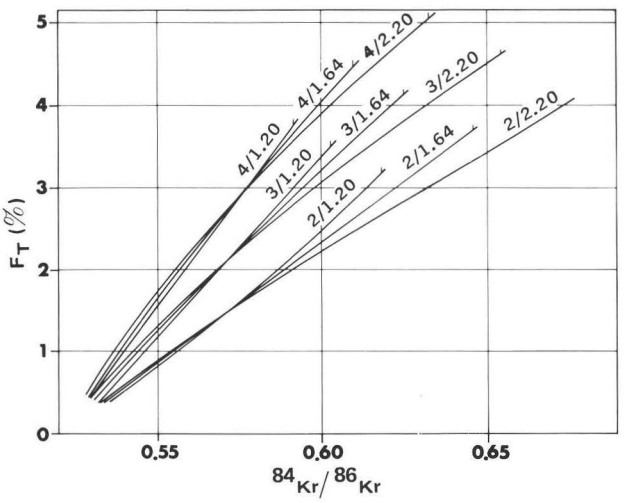


Fig. 3

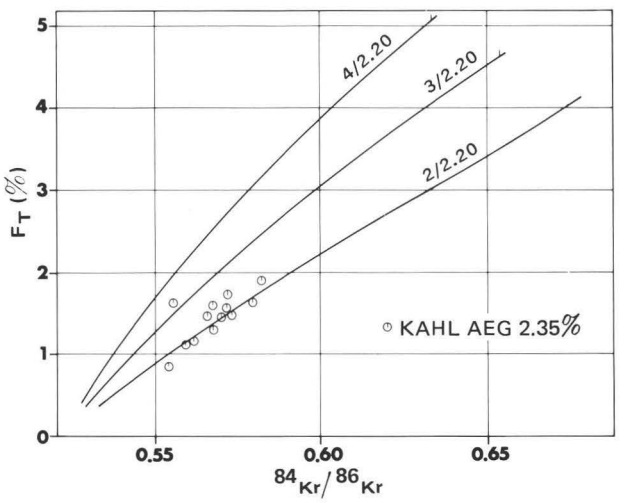


Fig. 4

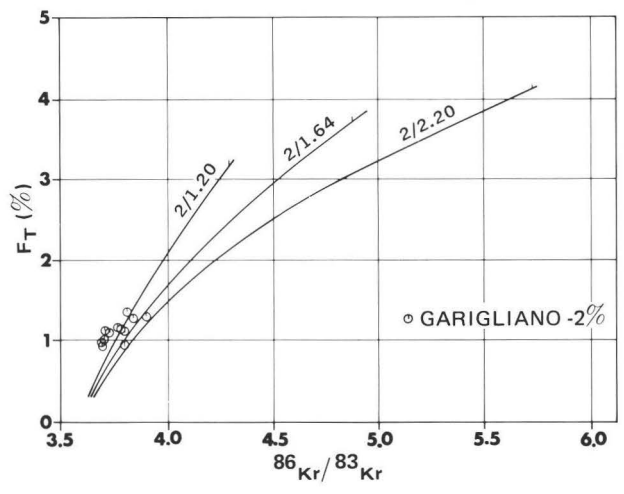


Fig. 5

References

1) R. BERG, C. FOGGI, L. KOCH, R. KRAEMER, F.J. WOODMAN, Value and Use of Isotopic Correlations in Irradiated Fuels, Symp. on Practical Aspects of R&D in the Field of Safeguards, Rome (1974)

2) A. SOLA: ISOTEX-1 – Code de Calcul de concentrations isotopiques et de rapports de concentrations, EUR 5111 (1974)

3) C. FOGGI, W.L. ZIJP, Data Treatment for Isotopic Correlation Technique – Symp. on Safeguarding of Nuclear Materials, Vienna (1975)

4) C.V. SMITH, H.A. VIEWEG: GGC-II – a Program for Using the GAM-II and GATHER-II Spectrum Codes in Preparing Multigroup Cross-sections Input on Punched Cards ... – General Atomic report, GA-4436 (1963)

5) C.M. LEDERER, J.M. HOLLANDER, I. PERLMAN, Table of Isotopes, Wiley and Sons, New York (1967)

6) R. GUNNINK, J.B. NIDAY, R.P. ANDERSON, R.A. MEYER, Gamma Ray Energies and Intensities, Lawrence Radiation Lab. Report, UCID 15439 (1969)

7) J.F. EMERY, S.A. REYNOLDS, E.J. WYATT, G.I. GLEASON, Half-lives of Radionuclides-IV, *Nucl. Sci. and Eng.*, **48**, (1972) 319-323

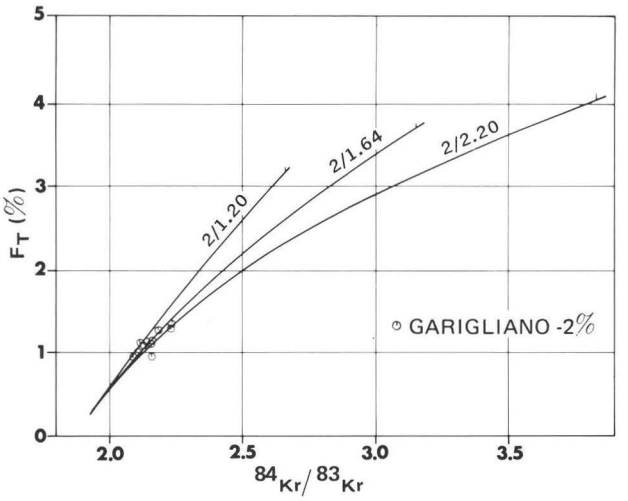
8) M. BRESESTI et al., Post-irradiation Examination of a Fuel Assembly Discharged from the Trino Vercellese Reactor after the 2nd Irradiation Cycle. Report EUR (in preparation)

9) A. ARIEMMA, L. BRAMATI, M. GALLIANI, M. PAOLETTI GUALANDI, B. ZAFFIRO, A. CRICCHIO, L. KOCH, Experimental and Theoretical Determination of Burnup and Heavy Isotope Content in a Fuel Assembly Irradiated in the Garigliano Boiling Water Reactor, EUR 4638 (1971)

10) L. KOCH, P. HOCHSTEIN, P. POHL, U. WOLFF, Nachbestrahlungsuntersuchungen eines Brennelementsbündels des VAK-Reaktors und Vergleich mit Rechnungen, EUR 4690 (1971)

11) A.L. POPE, J.S. STORY, Thermal Average, Resonance Integral and Fission-Spectrum Average Neutron Capture Cross-sections of Nuclides with Z = 30 to 68, Proc. of a Panel on Fission Product Nuclear Data, Bologna (1973) IAEA-169

12) A.M. BRESESTI et al., Post-irradiation Analysis of Trino Vercellese Reactor Fuel Elements, EUR 4909 (1972)



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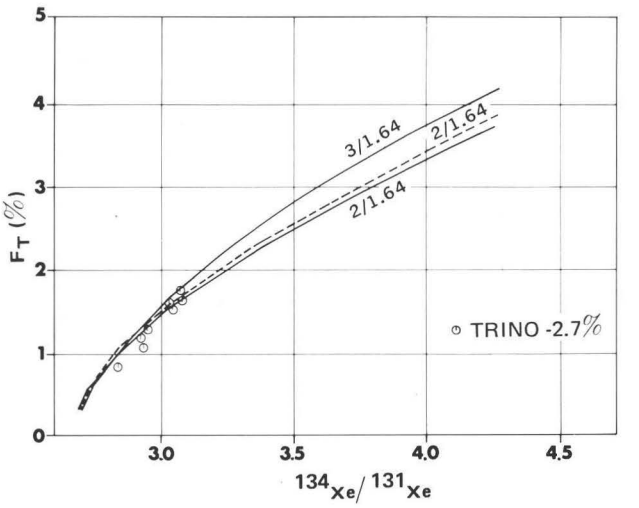
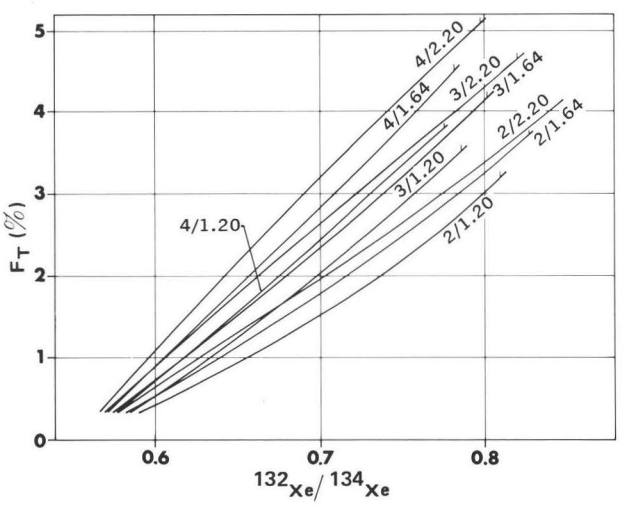


Fig. 9



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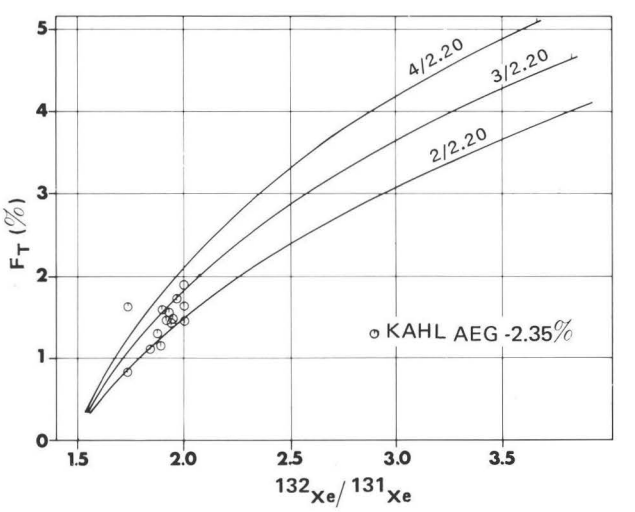
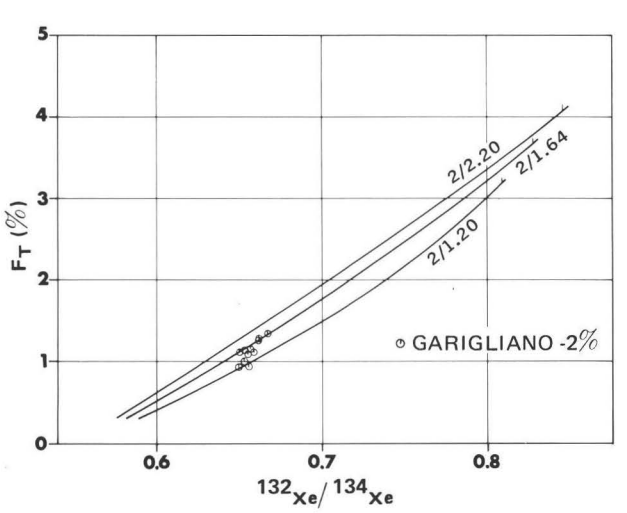


Fig. 10



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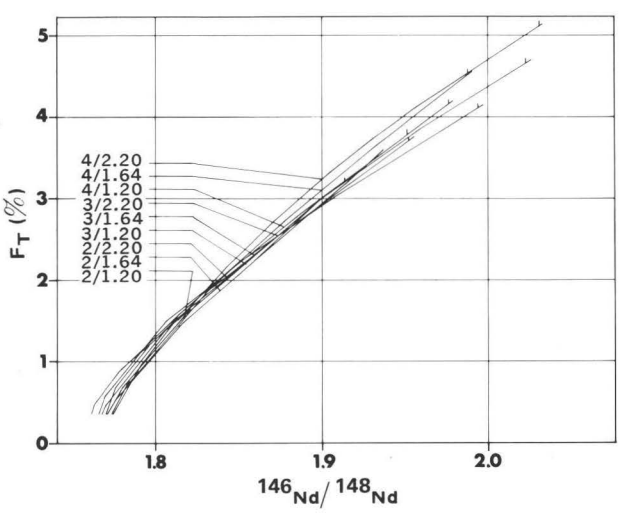

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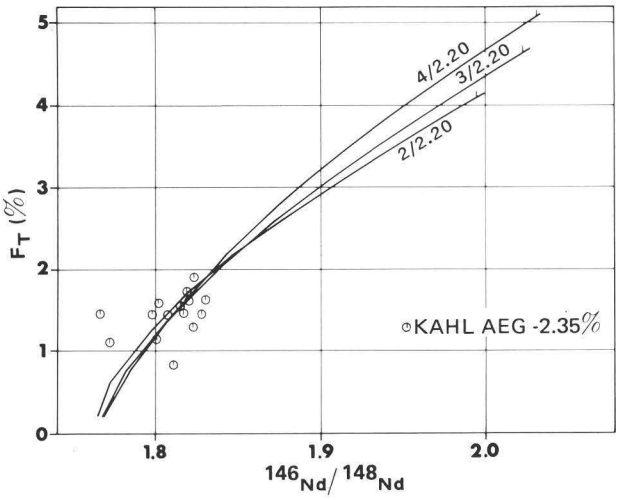

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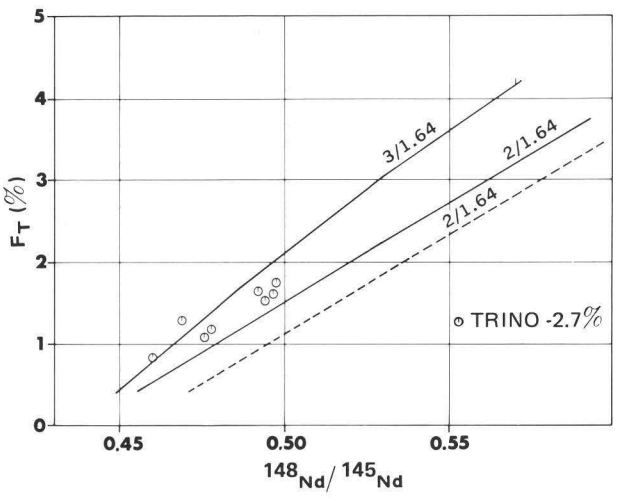

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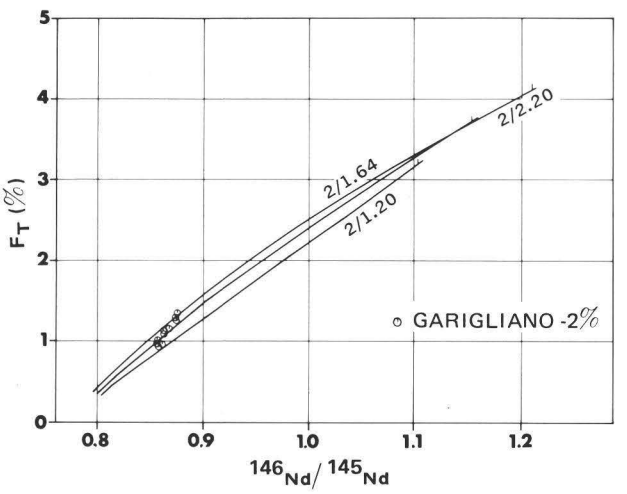

Fig. 14

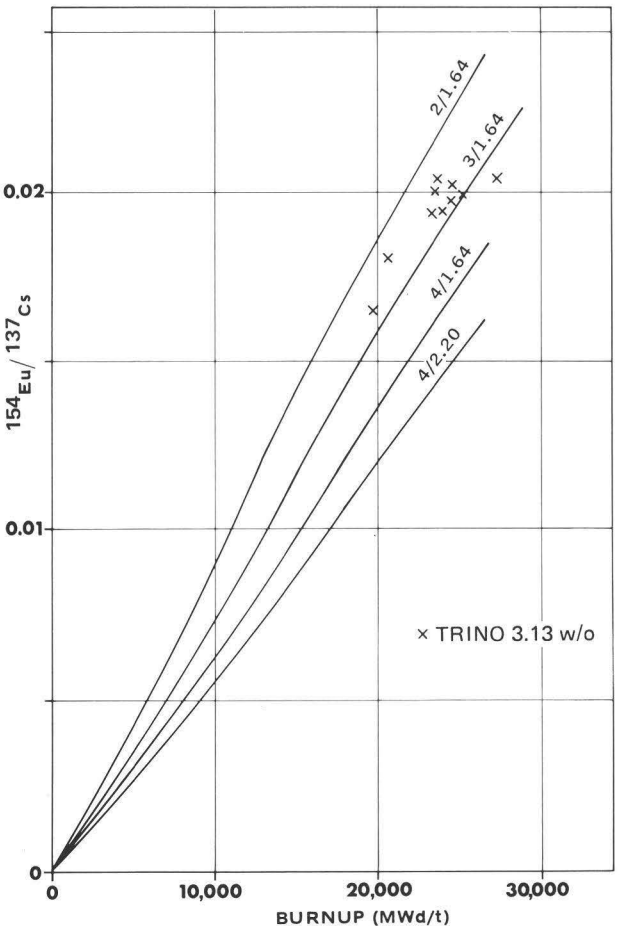

Fig. 15

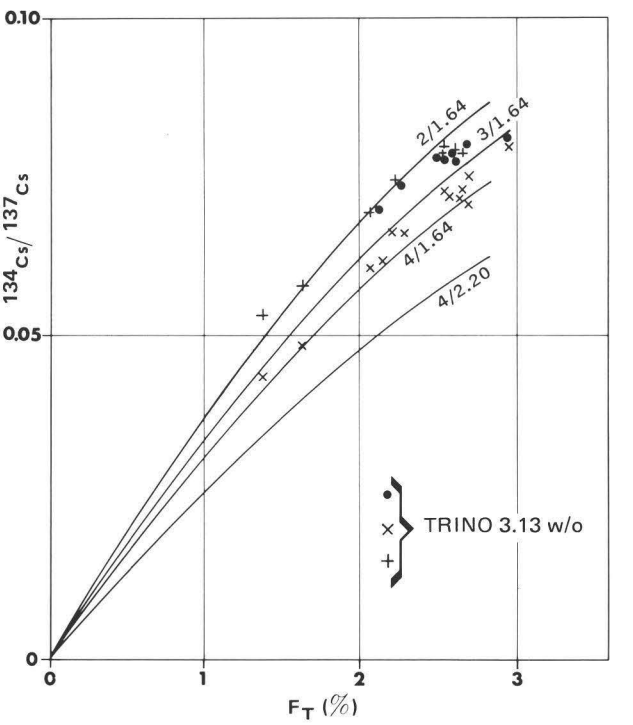

Fig. 16

Totem: a Computer Program for the Analysis of Power-Station Installation Policies

F. Conti, G. Graziani

Introduction

Various calculation methods are commonly employed to evaluate the power-plant installation policies which might be followed to satisfy a given electric energy demand. They can be grouped into optimization methods and simulation methods.

Optimization Programs

These rely on mathematical optimization techniques. The objective function is in general the present-worth total cost of the electric energy production in the period under investigation; it can, however, be another function of the installed capacity and of the energy produced by different types of plant (i.e. total expenditures due to imports from outside the system, total fuel consumption, and so on).

Simulation Programs

These calculate the materials balance sheet and economics for a given installation policy. With these codes the optimization of the policy can be carried out by performing a set of parametrical investigations.

Both types of program are available at the JRC Ispra, the most commonly used being the optimization code INTAT and the simulation code POPE. Unfortunately these codes work with simplified hypotheses, mainly concerning the load-duration curve and the fuel cycle scheme, and use input data which require previous elaboration. In particular, difficulties arise from the fact that the input to the problem is usually the total electrical energy demand, whilst these programs use the generating capacity as an input. Furthermore, they do not distinguish between plants of different ages and a maximum utilization as function of age cannot be imposed.

The code TOTEM was written to overcome these drawbacks and to introduce other improvements described below. In TOTEM the splitting of the total energy production between various types of station is assumed to be given (with the exception of an option, described below, where a certain degree of freedom is left to the fast breeders in order to make full use of the available plutonium). The code evaluates the installation policy, fuel consumption and fuel production, separative work, fabrication and reprocessing capacity requirements, expenditures and capital investments consequent to any given repoduction patterns.

Description of the Program

Its first task is to deduce from the energy requirements given as input the generating capacity that must be installed in order to satisfy that demand. This calculation is not straightforward, for a number of reasons, e.g.:

1. The energy required is distributed in time according to a given load-diagram (load duration curve).
2. The max. utilization (max. availability curve) of any type of station is a function of its age (load factor history).
3. A minimum power reserve to be provided.

TOTEM splits the load diagram amongst the various stations, which are divided by type and age-group. The splitting is performed according to the following rules:

- for a few type of station the position in the load diagram (average load factor) is given (hydroelectric stations, privileged base-load stations, peak-load stations). They are called here "FATAL" stations;
- for the other stations the position in the load diagram is allocated according to a given priority list (per type and age-group), established according to economic competitivity.

Having done this, the code knows the age and the load factor of each type of station.
A few main options are worth mentioning:

a) Plutonium Balance

Although the energy produced by each type of station is given in input, the plutonium produced does not necessarily match with the plutonium consumed. Therefore there will be a positive or negative plutonium stock. An alternative way to operate the code is possible, in case the system is considered to be closed (no Pu sale or purchase): a part of the energy demand is left free for the fast breeders (or any plutonium burner) to satisfy it, according to the plutonium available, the starting year and the industrial constraints (maximum installation rate). The rest will be filled by another type of station defined in the input: in the event that the fast breeders cannot be installed at the necessary rate, the other types of station contribute to satisfy the demand, according to a given preference list and to constraints on their maximum installation rates.

b) Decision not to Install New Power Stations of a certain Type after a Given Year

A typical use of this option is to evaluate the maximum feasible increase of nuclear capacity, if a given type of conventional power station is not built any more after a given year.

The minimum values of energy production by the remaining types of station are given as input. The difference between this and the total, resulting from the closing down of the obsolescent conventional stations, is distributed among the other stations according to a preference list and to constraints on their installation rate.

c) Storage of Energy by Pumping Water into Reservoirs

Having performed an estimation of the available reservoirs, one can then give as an input the energy provided by them and its position in the load diagram.

This being a "secondary" form of energy, the corresponding area of the load diagram is actually not directly required from the system, and it is shifted to another part of the load diagram, to the extent permitted by the existence of non-utilized capacity. In other words, the load diagram is modified, a flatter and more convenient shape being obtained.

d) Input Correction

This is actually not an option, but a permanent feature of the code. The installation policy conceived as an input may be unsatisfactory, since a few details cannot be appreciated without previous calculations; the installation required for one or more types of station may be larger than admissible, taking into account the minimum doubling time. In this case more energy production is assigned by the code to other types of stations, following a given preference list: the next type is assigned a larger demand as far as is compatible with installation constraints, then the next type and so on.

e) Calculation of the Reserve

In every year, the reserve is defined as the percent difference between the total installed capacity and the total peak power demanded. Once the allocation procedure and the installations have been completed, the program calculates the reserve, the value of which can be different from the one required and given in input. If it is larger, no problems arise; the safety margin for the power system is satisfied and the reserve value, larger than required, is due only to the installation policy followed up to that year. If, on the contrary, the calculated value of the reserve is smaller than the input value, more power plants have to be installed in order to match this value.

To avoid a situation in which the new plants are allocated only for reserve purposes, the allocation procedure must be completely repeated for a modified load diagram, obtained from the original one to which is added a power step with zero utilization hours. As a result a lower utilization of the more aged and priority unfavoured plants will be obtained, whilst the new plants are in any case placed in the base load.

f) Reprocessing Plant Constraints

The lack of construction of a sufficient reprocessing capacity may be a serious bottleneck in the development of the nuclear power stations and as well as leading to a much higher requirement of natural uranium it may affect the introduction of fast breeder reactors, if the plutonium fuel is not available in time and in sufficient quantity.

The code simulates that the heavy metal discharged is stockpiled, separately for each reactor type. Up to 5 reprocessing plants are envisaged, to process various types of fuel elements. The reprocessing capacity of each plant as a stepwise function of the time must be given in input. In each year, each reprocessing plant processes the stockpiled HM quantities, according to its capacity. If the HM stock exceeds the reprocessing capacity, the difference is added into the stock of the succeeding year.

Each outflow from the reprocessing plants (U nat equivalent, U depleted, Th, S.W., Pu, ^{233}U) is added to each material stock, taking into account the time lags.

g) Possibility of Evaluating Pollution Charge

If required, the code calculates the pollution associated with a given power-station strategy. The contribution that each plant in the whole fuel cycle (fabrication, reactor, reprocessing plant) makes to pollution is taken into account.

The total pollution quantities (annual and cumulative) and the associated radio-activities are listed out.

The annual and cumulative pollution due to the SO_2 produced in conventional oil-field power stations is also quoted.

Another output item of interest is the total amount of waste heat from power plants.

These data are very useful in the evaluation of the cooling needs and the plant siting problems.

h) Use of Excess Plutonium in the LWR Cycle

In some calculations it can occur that an excess of plutonium is stockpiled in the final portion of the period under investigation.

If at that time plants are still present which employ enriched uranium for their refuelling charges, it might be desirable to employ the plutonium stock created, in order to reduce the separative work and the exploitation of natural uranium resources.

Using this option the cycle of one plant (i.e. LWR) can be replaced in part or wholly by the corresponding plutonium cycle.

Input Data

Among the various input options, there are two which are worth mentioning here.

Detailed Evaluation of Specific Reactor Data on Material Flow

Specific reactor data on material flows are not always available in the form required by the code. More usually such data as burn-up, specific power, efficiency and charge and discharge enrichments are available. These reactor data are processed in a subroutine that gives, as output, the specific consumption and production averaged over all reactor zones.

Furthermore, the fuel requirements for the first core can be evaluated from specific power, efficiency and enrichment data. Consequently the material flows are now computed in terms of the first core and no longer in terms of inventory as previously done, in the version 1 of the code.

Detailed Evolution of Economic Data

Optionally, the proportional costs of a power plant can be either given as input data or calculated in detail, starting from the typical fuel cycle cost data (uranium enrichment, fabrication, reprocessing costs, and so on). The capital investments are assumed to be distributed over the plant construction time according to an S-curve.

Output Results

In the output the following results are printed:

a) for every reactor type
   1. inventory-dependent fuel requirements
   2. energy-dependent fuel requirements
   3. total fuel requirements

b) total differential fuel requirement summed over all plant types, including conventional stations i.e. coal, fuel oil and natural consumptions.

c) total integrated fuel requirement for all plant types.

Fuel Requirements and Production

Once the whole strategy has been determined as to both energy and capacity, the calculation of the fuel requirement and production is quite straightforward, the specific values for each plant type being fed in as input.

The loading and discharging scheme of a reactor is well known, but it was decided to simplify the model.

After the first core loading, a reactor is assumed to run without any fuel discharge for a period δ_B, which is different from the normal reloading interval τ. As the code in general deals not with a single reactor but with a huge number of power stations, and moreover because it is not true that the reloading interval is constant, (the reloading time may vary with the plant load factor, it depends on an integrated fuel management for the whole net that cannot be considered in this code, etc.), it is assumed that from the first reloading time (δ_B) onwards every reactor works on a continuous charge-discharge scheme, under equilibrium conditions.

The following items of general interest are calculated by the code:

1) fabrication throughput, at entry to fabrication plant
2) reprocessing throughput, at entry to reprocessing plant
3) natural uranium requirements, at mine
4) thorium requirement, at mine
5) separative work requirements
6) depleted uranium, at exit from enrichment plant
7) artificial fissile (plutonium and U-233) stocks, at exit from reprocessing plant
8) running cost
9) capital investments

The expenditures can be converted to a present-worth basis, the discount rate being one of the input data.

The specific data for inventory and consumption must include the losses, if any, that occur in the fuel cycle operations between the reactor and the point of the fuel cycle where the requirement or production quantities are evaluated.

The times required for each fuel cycle operation must be given in input for a proper evaluation of the year in which the material throughputs and stocks, as indicated in items 1-7 are affected by the installation policy and by energy produced in the current year N.

The TOTEM computer program is operating on the IBM 370 computer. It allows detailed simulations for as many as 10 different plants and for a maximum period of 60 years. Computer times are of the order of 1 to 2 minutes for a single run. The program has been successfully tested and it is now a useful tool for the analysis of policies on future power-station installation in the Community.

The Angular Flux of Gamma Rays in a Plane Iron Shield

H. Penkuhn

In a previous paper (to be published as EUR-ESIS report) the author treated the problem of the angular flux of gamma rays in a normal concrete shield. In a bulk reactor shield, however, there are often steel liners and plugs.

A good knowledge of the angular fluxes in steel will allow a realistic estimate of the gamma streaming in the narrow tolerance gaps between the plugs and liners. In order to simplify the problem, we replace the steel by iron of density 7.8 g/cm^3 (this is justified for pure gamma problems) and consider source energies from 0.662 to 6 MeV and penetrations from 6 to 60 cm. Let the source be an iron slab, 15 cm thick, with isotropic and homogeneously distributed sources. The unscattered angular flux $\phi^{(o)}$ (x,ω) (ω = cos φ, φ = angle between shield axis and photon direction) is for positive ω :

$$\phi^{(o)}(x, \omega) = A\,\omega^k \exp(-\mu_o x/\omega) = A\omega^k \exp(1-/\omega)\mu_o x$$

where A = normalisation constant; k = 0 means (as here) an isotropic angular flux at the boundary at x = 0, k = 1 means a cosine-source at x = 0, etc.; μ_o = attenuation coefficient at the source energy E_o. We develop $1/\omega$ and then exp(-1/ω) in powers of (1 − ω) and get finally, using the polynomial series:

$$\phi^{(o)}(x,\omega) \approx A\exp(-\mu_o x)\;\omega^{k+\mu_o x}\left[1 - \frac{\mu o x}{2} <^1 - \omega >^2 .....\right]$$

We integrate this approximation over the whole solid angle:

$$\phi^{(o)}(x) \approx \frac{2\pi A e^{-}\mu_o x}{k+\mu_o x+1}\left[1 - \frac{1-k/(k+\mu_o x)}{k+\mu_o x+2}\right] \approx \approx \frac{2\pi A e^{-\mu_o x}}{k+\mu_o x+2}$$

(the last approximation is valid for very great k $+\mu_o$x). The exact result is 2π A$\cdot E_{k+2}(\mu_o x)$; our approximation is exact at x = 0, and for great μ_ox it agrees well with the asymptotic expansion of the exponential integral $E_1(z)$.

We compute the scattered angular energy fluxes $\phi_E^{(s)}$ (x,ω) with our numeric transport program PIPE (EUR 4624.e); they cannot be calculated analytically.

Fig. 1 shows the angular behaviour of the scattered gammas for the highest and lowest source energies (6 and 0.662 MeV) and the greatest and smallest penetration (60 and 6 cm). $\phi_E^{(s)}$ (x,ω) changes by a factor near 500 for 6 MeV at 60 cm, but only by a factor near 30 for 0.662 MeV at 6 cm, if $\omega = \cos\varphi$ changes from +1 to -1. Near $\omega = 1$ the angular energy flux is strongly space-dependent; we approximate for 6 cm ≤ x ≤ 60 cm and $\omega \geq \omega_L$:

$$\phi_E^{(s)}(x,\omega)/\phi_E^{(s)}(x,1) = \omega^{n(s)}(x), \text{ with}$$

$$n^{(s)}(x) = (\alpha\mu_o x - \beta)^{\gamma}(1+\rho\%) \text{ for } \omega \geq \omega_L$$

(ρ here and ρ_i later are the maxima of the deviations, no averages). Table 1 shows the parameters α, β, γ, and ρ as functions of E_o :

Table 1 : Parameters defining $n^{(s)}$ in iron

E_o(MeV)	α	β	γ	ρ	ω_L
6	1.25	0.992	0.8	9	0.8
3	1.53	1.257	0.7	14	0.8
1.25	1.95	2.14	0.6	11	0.9
0.662	3.00	5.24	0.5	18	0.9

A comparison of these "directional exponents" $n^{(s)}$ in iron and concrete yields identical curves for E_o = 3 MeV and maximum differences of ±5% for E_o = 6 MeV and E_o = 1.25 MeV. Only for E_o = 0.662 MeV so the deviations become important: for $\mu_o x \geq 4$ $n^{(s)}$ is higher in Fe than in concrete by 10-15%. For great φ ($\varphi \geq 50°$) the form of the spectrum tends to be independent of the spatial coordinate x, as shown in Fig. 1. We approximate:

$$\phi_E^{(s)}(x,0)/\phi_E^{(s)}(x,1) = a(\mu_o x)^b(1 \pm \rho_1), \quad 6 \text{ cm} \leq x \leq 60 \text{ cm}$$

$$\frac{\phi_E^{(s)}(x,\omega)}{\phi_E^{(s)}(x,0)} = \left\{ \begin{array}{l} \exp(c\omega)(1 \pm \rho_2),\ 0 \leq \omega \leq 0.6 \\ (1-\omega)^d(1 \pm \rho_3),\ -1 \leq \omega \leq 0.0 \end{array} \right\}$$

$$12 \text{ cm} \leq x \leq 60 \text{ cm}$$

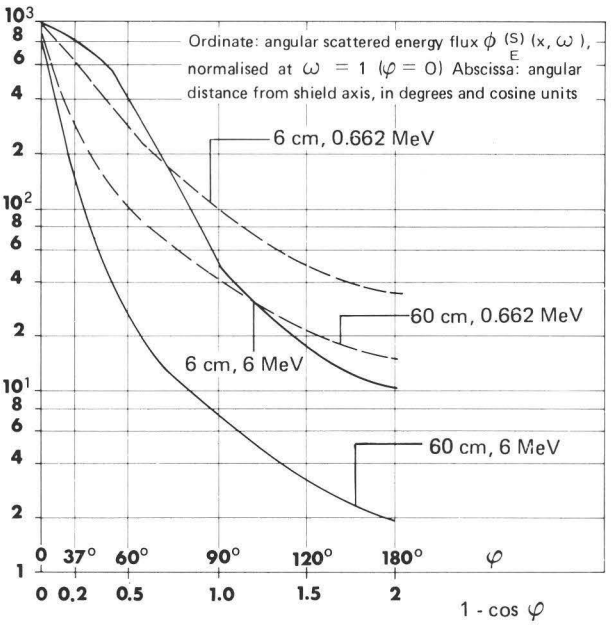

Fig. 1 : Angular Energy Flux in an Iron Shield

Table 2 shows a, b, c, d, ρ_1, ρ_2, and ρ_3 vs E_o.

Table 2 : Parameters for the angular fluxes in iron for $\omega \leq 0.6$ (Values in parentheses refer to light concrete)

E_o(MeV)	a	b	ρ_1(%)	c	ρ_2(%)	d	ρ_3(%)
6	0.0649 (0.0667)	-0.888 (-0.888)	5	3.66 (3.6)	34	-1.88 (-1.65)	11
3	0.0949 (0.1098)	-0.737 (-0.722)	5	2.89 (2.8)	23	-1.76 (-1.55)	8
1.25	0.137 (0.166)	-0.52 (-0.433)	5	2.31 (2.23)	16	-1.55 (-1.3)	4
0.662 (0.7)	0.152 (0.207)	-0.395 (-0.332)	6	2 (1.8)	12	-1.44 (-1.14)	5

Here again we note substantial differences between iron and concrete only at low E_o. The high deviations – up to 34% – from our fits in the range $0 \leq \omega \leq 0.6$ are due to the fact that the space dependent spectrum near $\omega \sim 1$ conditions this range in its neighbourhood, especially if E_o is high, and this makes a space-independent fit difficult.

A last question: all these curves and fits describe the angular energy flux $\phi_E^{(s)}$, in MeV/(cm^2 sec sterad); but what about the dose-rate angular flux ? Table 3 shows the minima and maxima of the differences between

$$D_{REL}^{(s)} = D^{(s)}(x, \omega)/D^{(s)}(x, 1)$$

and

$$\phi_{E,REL}^{(s)} = \phi_E^{(s)}(x, \omega)/\phi_E^{(s)}(x, 1).$$

The changing signs of the differences are a consequence of the form of the energy-dependence of the dose-rate weighting coefficient $\mu_{EA}(E)$: it has a flat maximum at 0.5 MeV and a minimum at 90 keV.

All these relative scattered fluxes can be normalized by using the well-known and often tabulated build-up factors; with $\phi_E^{(o)}(x)$ = unscattered total energy flux and $B_E(x)$ = energy buildup factor, one can write:

$$B_E(x)\,\phi_E^{(o)}(x) = \int\int_{4\pi} d\Omega\,[\phi_E^{(o)}(x, \omega) + \phi_E^{(s)}(x, \omega)]$$

$$[B_E(x) - 1]\,\phi_E^{(o)}(x) = 2\pi \int_1^1 d\omega\,\phi_E^{(s)}(x, \omega)$$

Table 3 : $D_{REL}^{(s)} - \phi_{E,REL}^{(s)}$ in %

	ω - ranges				
E_o(MeV)	-1 to -0.3	0 to 0.3	0.6	0.8	0.9 to 0.97
6	29 to 41	8 to 42	0 to 31	0 to 13	0 to 5*
3	11 to 20	7 to 22	1 to 18	0 to 10	0 to 5*
1.25	-2 to -7	-1 to 2	1 to 3	1 to 3	0 to 2
0.662	-7 to 13	-3 to -5	-1 to -3	0 to -1	0 to -0.5

* *for $\omega = 0.97$ only 0-2%, for $\omega = 0.9$ 0-5%*

and a similar equation is valid for the dose-rate fluxes if related to the dose-rate ("exposure") build-up factor $B_D(x)$.

In the meantime two EUR-ESIS reports about these calculations have been published (5286 and 5373e). But all these results refer to thick sources (15 cm); in order to know more about thin slab sources, the calculations were repeated with the source thickness D = 1 cm (of iron). We define

$$\phi_{E,R}^{(s,D)}(x,\omega) = \phi_{E}^{(s,D)}(x,\omega) / \phi_{E}^{(s,D)}(x,1)$$

(= scattered angular energy flux normalized on the shield axis direction at $\omega = 1$, from a source of thickness D).
We compare the cases D = 1 cm and D = 15 cm and obtain

$$\Delta Q_{E,R}^{(s,1,15)} = [\phi_{E,R}^{(s,1)} - \phi_{E,R}^{(s,15)}] / \phi_{E,R}^{(s,15)}$$

(the common variables x and ω are omitted). This ΔQ is positive for all our x from 6 to 60 cm penetration depth along the axis (x = distance from dose point to source surface plane near the shield) and for all our ω_i ($-1 \leqslant \omega_i \leqslant 0.97$). But at $\omega_i = 1$, ΔQ vanishes since

$$\phi_{E,R}^{(s,D)}(s,1) = 1$$

for all x and D (by definition). A positive ΔQ means that the thin source causes a less anisotropic energy flux than the thick source (at least for $X \geqslant 6$ cm).

Fig 2 shows some results for E_o = 6 MeV, and Table 4 shows at which source distances x (in cm) and μox (in mfp) the relative difference ΔQ falls below the limits 9%, 15%, 31% and 51%. ΔQ decreases with increasing x and with decreasing source energy E_o.

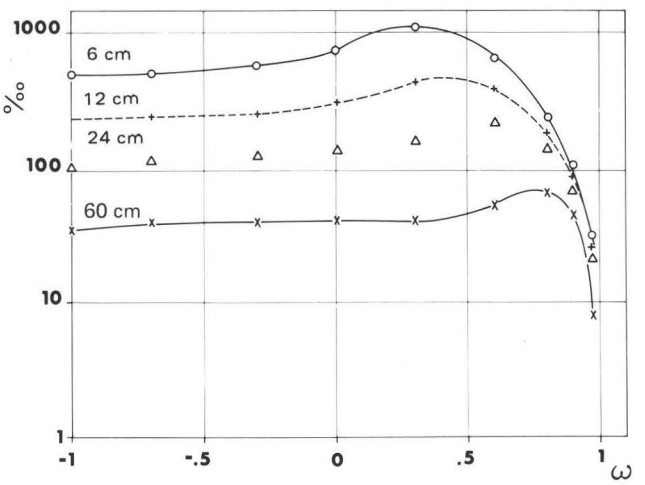

Fig. 2 : $(\phi_{E,R}^{(S,1)} - \phi_{E,R}^{(S,15)})/\phi_{E,R}^{(S,15)}$ in ‰; Abscissa = ω = directional cosine. Source energy = E_O = 6 Mev. Parameter : penetration x in cm

Table 4 : Source distances (rounded) in mfp (values in cm in parentheses) above which $\Delta Q_{E,R}^{(s,1,15)}$ is below the limits (in %) given in the first line; specified for different angular (cosine) ranges and source energies E_o

Limits for ΔQ	9%			15%			31%			51%		
ω-range / E_o(MeV)	0.9 to 1	-1 to 0	all ω	0.87* to 1	-1 to 0	all ω	0.77 to 1	-1 to 0	all ω	0.65 to 1	-1 to 0	all ω
6	2.6 (11)	8 (34)	11 (46)	1.4 (6)	5.2 (22)	7.8 (23)	1.4 (6)	2.8 (12)	4 (17)	1.4 (6)	2.1 (9)	2.6 (11)
3	2.3 (8)	6.8 (24)	9 (32)	1.7 (6)	5.1 (18)	6.2 (22)	1.7 (6)	2.8 (10)	3.6 (12)	1.7 (6)	1.7 (6)	2.5 (9)
1.25	2.5 (6)	5.8 (14)	6.4 (16)	2.5 (6)	4.6 (11)	2.5 (12)	2.5 (6)	2.5 (6)	2.5 (6)	2.5 (6)	2.5 (6)	2.5 (6)
0.662	3.4 (6)	5.7 (10)	6.2 (11)	3.4 (6)	3.4 (6)	3.9 (7)	3.4 (6)	3.4 (6)	3.4 (6)	3.4 (6)	3.4 (6)	3.4 (6)

* *If $E_o \leqslant 1.25$ MeV this limit applies already for $0.8 \leqslant \omega \leqslant 1$*

An example of how to read Table 4: for E_o = 3 MeV, the form of the scattered angular energy flux spectra of the thin source is higher than that of the thick source by at most 9%; a) in the range $\omega \geqslant 0.9$, if $x \geqslant 8$ cm $\approx$ 2.3 mfp; b) in the range $\omega \leqslant 0$, if $x \geqslant 24$ cm $\approx$ 6.8 mfp; and c) in the whole ω range, if $x \geqslant 32$ cm $\approx$ 9 mfp. The value x = 6 cm appears often in Table 4 since it is the lowest of the discrete source-distances considered; if x-values below 6 cm were also to be included, most (not all) of the entries "6 cm" would have to be lowered. But Table 4 says nothing about the spatial range under x = 6 cm. The highest occurring ΔQ-values are for 6 MeV 112%, for 3 MeV 73%, for 1.25 MeV 31% (all at x = 6 cm and ω = 0.3), and for E_o = 0.662 MeV 18% (at x = 6 cm, ω = 0.6).

The results in Table 4 and Fig. 2 can be explained qualitatively: only if μox is not great and if also ω is not near unity, the dose point in the shield "sees" that the 1-cm source is optically thin in the direction $\omega = 1$ (shield axis),

but tends to be optically thick in the ω-directions far from unity: if D = 1 cm, we have μ_o D $<<$ 1, but μ_o D/ω is no longer much smaller than unity. Thus in one direction the dose point sees a thin source, in the other a thick one, if D = 1 cm; but if D = 15 cm, the dose point sees thick sources everywhere towards the source slab; this explains the difference. But if ω is near one, the dose point sees thin sources for ω = 1 and $\approx$ 1, in both directions the source strength is reduced by a nearly equal factor, compared with the thick source with D = 15 cm. And the same reasoning holds for all ω if μox $>>$ 1, since then nearly all photons are generated by those which have travelled near the axis direction with $\omega \approx 1$ (the others with ω far from 1 – more precisely those with μox/ω – μox $>>$ 1 – are absorbed much faster).

For $-1 \leqslant \omega_i \leqslant 0.3$ the following fit is possible:

$$\Delta Q_{E,R}^{(s,\,1,\,15)}\ (x, \omega) = A\ (12\ cm/x)^B\ (1 \pm P\%)$$

Table 5 shows A, B, and P as functions of E_o and ω; (the deviations P $\geqslant$ 15% are due to rounding errors, and they are of small importance where ΔQ is below few %).

Table 5

E_o (MeV)	ω_i = -1			ω_i = 0			ω_i = 0.3		
	A	B	P	A	B	P	A	B	P
6	0.225	1.1	6	0.307	1.25	2	0.405	1.41	6
3	0.171	1.1	4	0.208	1.3	7	0.256	1.337	9
1.25	0.084	1.25	15	0.103	1.46	11	0.118	1.46	9
0.662	0.046	1.35	17	0.056	1.55	8	0.062	1.585	9

We see from Table 4 and 5 that the lower the source energy E_o, the lower is the sensitivity to the source thickness change. The main reason is that for E_o = 6 MeV 1 cm is optically thin – 1 cm = 0.24 mfp – but for E_o = 0.662 MeV we have 1 cm = 0.57 mfp, the 1-cm slab tends already to get optically thick and approaches the 15-cm slab source (but if the shield material changes, $\phi_{E,R}^{(s)}$ (x, ω) is more sensitive at lower E_o.).

Table 6 shows, for E_o = 6 MeV and 1.25 MeV, limits for the difference between the scattered relative angular dose rate – $D_R^{(s,1)}$ (x, ω) – and $\phi_{E,R}^{(s,1)}$(x, ω). A comparison with Table 3 shows negligible differences for E_o = 1.25 MeV: the corresponding limits for D = 1 cm and D = 15 cm differ only by ± 1%. For E_o = 0.662 MeV the deviations should be still lower. But for E_o = 6 MeV only the upper limits coincide within ± 1%; the lower limits are below

Table 6 : $D_R^{(s,1)} - \phi_{E,R}^{(s,1)}$ in %, upper and lower liçits vs. E_o and ω_i; for 6 cm $\leqslant$ x $\leqslant$ 60 cm

E_o \ ω_i	-1	-.7	-.3	0	0.3	0.6	0.8	0.8	0.97
6 MeV	30	30	31	23	2	-7	-1	-1	0
	36	38	41	41	42	30	13	5	2
1.25 MeV	-6	-4	-1	0	1	0	0	0	0
	-7	-5	-2	1	2	3	3	2	0.5

those of D = 15 cm by at most 7 % for $0.3 \leqslant \omega_i \leqslant 0.6$ and by at most 4% for $\omega_i \leqslant 0$; for $\omega_i \geqslant 0.8$ they differ again only by ± 1%. But if only the range x $\geqslant$ 12 cm is regarded for D = 1 cm, the same upper and lower limits (± 1%) can be applied as for D = 15 cm and 6 cm $\leqslant$ x $\leqslant$ 60 cm. For E_o = 3 MeV one can interpolate in E_o between 6 MeV and 1.25 MeV.

In order to interpolate in the source thickness D one should plot $\phi_{E,R}^{(s,\,D)}$ over the "saturation degree" of the source slab:

$$SD = 1 - \exp(-\mu oD)$$

(SD is proportional to the unscattered angular flux for ω = 1). Table 7 shows that the case D = 3 cm is nearer to D = 15 cm for E_o = 0.662 MeV, but nearer to D = 1 cm for E_o = 6 MeV.

Table 7 : Saturation degree SD vs. E_o and D

D(cm) \ E_o(MeV)	0.662	6
1	0.43	0.21
3	0.82	0.51
15	0.9998	0.972

Data Processing and Interpretation for the remote Sensing of Earth Resources

J. Mégier

Introduction

To meet the needs of the AGRESTE project [1] – application of remote sensing of Earth resources by satellite to agriculture and forestry – a data-processing team was formed at Ispra to handle the data from the LANDSAT satellite. The matter was so urgent that it was decided to adopt, at any rate for a start, conventional methods of automatic data processing and selection that had, in the main, been proven in other fields. The algorithms for applying these methods were either already available at other laboratorie [2] or were developed at Ispra.

One of the primary aims of AGRESTE is to determine how far it is possible to obtain an inventory of the acreages under rice and poplar in European farming and forestry conditions; this is the problem that we shall consider in the following pages, after briefly reviewing the techniques employed.

Methods Used

With the LANDSAT satellites, the resolution of the data on the ground is of the order of 80x80 m^2, and each resolution element (RE) is represented in the measurement space by the values of that element's spectral responses to the ground in the four optical channels available on the satellite, i.e. in the wavelength bands (in μ) 0.5 - 0.6; 0.6 - 0.7; 0.7 - 0.8 and 0.8 - 1.1 (near-infrared). The spectral responses are digitalized into discrete integer values between 0 and 127 for the first three channels, and between 0 and 63 for the last one.

Data Processing Using Single Channels or Channel Ratios

In this simple case the REs of the zone to be processed have to be classified according to their spectral response in the selected channel. The classes are intervals in the field of variation of the response, which are chosen, for example, after examination of the histogram of the channel values for the zone. The same technique can also be applied to the ratios of the values in two channels.

"Learning" or "Supervised" Classification

All these methods use prior knowledge of certain zones of the scene to be processed, the identity of which is known. The statistical parameters of the distribution in those zones of the RE values (in the four channels) are then determined and they define the classes that will thereafter be used in the classification.

Euclidean or Angular Distance between Classes

Each of the different classes to which the vectors (RE) will be assigned is represented by its mean vector estimated in the respective reference zone and is limited by a membership threshold. We define a distance between vectors in the measurement space and assign each vector to the class to which it is nearest in this scheme, provided that it is not excluded from that class by the membership-threshold value; if it is so excluded from all the classes, the vector will remain unclassified.

In the simplest methods the distance employed is either the Euclidean distance $[(\underline{X}-\underline{Y})^T(\underline{X}-\underline{Y})]^{1/2}$ between the $\underline{X}$ and $\underline{Y}$ column vectors, or the angular distance $(\underline{X}, \underline{Y})$ which is related to the Euclidean distance D_N between the normalized vectors $\underline{X}/\|\underline{X}\|$ and $\underline{Y}/\|\underline{Y}\|$ by the relation $(\underline{X},\underline{Y}) = 2\sin^{-1}(D_N/2)$. The membership threshold is chosen as a function of the dispersion of the points (or vectors) round the mean vector of each class, expressed for example, in angular distance.

Non-parametric Linear Discrimination Functions

From the formal point of view the foregoing method may be characterized by the fact that it uses discrimination functions which are linear (for each class) and parametric in that the coefficients of the linear forms are provided by the mean vectors of the different classes. Hence, a formulation equivalent to the one described above consists in defining for each class C_i a discrimination function $f_i(\underline{X}) = M_i^T \underline{X} - 1/2\, \underline{M}_i^T\, \underline{M}_i$, where $\underline{M}_i$ is the mean vector of class C_i, and $\underline{X}$ is assigned to class C_k for which $f_k(\underline{X}) \geqslant f_i(\underline{X})$, $\forall_i$.

From this standpoint we can also at the outset define linear discrimination functions for each class, the coefficients of which will then be determined by iteration over the reference zones; more precisely, the coefficients of the linear forms are gradually modified in keeping with the results of classification of the reference vectors (whose membership class is known) by certain familiar techniques which would take too long to describe here [3]. All the reference vectors are thus "fed into the classifier" once and then a second time and so on until the classification results are stable, i.e. until all the vectors are correctly classed, on the hypothesis that linear separation of the classes is feasible, and in this case the convergence of the process is demonstrable [3] and effective. The discrimination functions thus defined are subsequently used to classify the unknown vectors. In the majority of cases the above hypothesis is not strictly valid, and then we can use for the discrimination function the set of coefficients that has given the bes-

classification results during a certain number of "learning" iterations over the reference zones.

Non-parametric Quadratic Discrimination Functions

The same viewpoint of "learning" by iteration over reference zones can be generally extended to include discrimination functions defined by quadratic forms of the vector coordinates in the measurement space. The linear class-separation hypothesis is thus avoided and the results will in general be better, at the cost of longer computing times (15 coefficients to be adjusted for each class, instead of 5 in the linear hypothesis, and with a measurement space of dimension four).

Maximum Likelihood for Normal Variables

In this context the probability distributions (or likelihoods) for each class $P(\underline{X}/C_i)$ are assumed to be known and normal. The decision rule concerns the reciprocal conditional probability $P(C_i/\underline{X})$ that the unknown vector $\underline{X}$ belongs to the class C_i, and this can be calculated by Bayes' formula, $P(C_i/\underline{X}) = [P(\underline{X}/C_i)\ P(C_i)]/P(\underline{X})$. The decision rule is then written:

$$P(\underline{X}/C_i)\ P(C_i) \geqslant P(\underline{X}/C_j)\ P(C_j),\ \forall_j \neq i \rightarrow \underline{X} \in C_i$$

where, if we write the law $P(\underline{X}/C_i)$ more explicitly and, for convenience, use the logarithms of the above expressions:

$$h_i\ (\underline{X}) \geqslant h_j(\underline{X}),\ \forall_j \neq i \rightarrow \underline{X} \in C_i$$

with

$$h_i(\underline{X}) = \log P(C_i) - 1/2 \log |\Sigma_i| - 1/2[(\underline{X} - \underline{M}_i)^T$$

$$\Sigma_i^{-1} (\underline{X} - \underline{M}_i)]$$

where Σ_i is the covariance matrix of class C_i, estimated over the sample constituted by the reference zone for that class, and $\underline{M}_i$ is the mean vector, similarly estimated.

The evaluation of $P(C_i)$, the ***a priori*** probability of existence of the class C_i in the scene to be processed, opens the door to a controversial problem of statistics, but a reasonable choice in the case of "supervised" classification consists in admitting equal ***a priori*** probabilities for all classes and therefore eliminating them in the decision rule.

Another controversy casts doubt on the normality of the vector distributions in the different classes; but here it should be remarked that although the decision rule given above is no longer theoretically optimum for non-normal distributions, nevertheless it defines a quadratic parametric classifier within the meaning of the section above.

Classification without Learning or Unsupervised

In this case the vectors of the scene to be processed are examined with no prior knowledge of the classes of interest. The classification algorithm defines a logic for aggregating the scene vectors into classes by means of a measure of inter-vector similarity (which may be the Euclidean or angular distance in the simplest cases) and a threshold of aggregation in the classes, similar to the membership threshold mentioned in section "Euclidean or angular distance between classes", which evolves during the working of the algorithm and may, for instance, be a function of the variance of the classes being constituted. The process may involve all the points (vectors) in the scene or only some of them chosen at random; in the latter case the remaining points are then classed, by one or the other of the techniques set out in "Learning or Supervised Classification", in the classes defined beforehand on the random sample. The points involved may be processed once only by the aggregation technique or several times in the course of successive iterations in order to obtain relative stability in the classes constructed and in the decisions on membership of points. Auxiliary techniques are also employed to reject poorly-representative aggregations, to amalgamate neighbouring aggregations, to increase the variance of the sample in cases of random sampling, and so forth. Needless to say, the various parameters governing the intensity of the agglomeration process, and hence the number and extent of the classes identified in the scene, remain subject to control and interpretation by the user.

Two simple methods that use these techniques have been tested; one uses the Euclidean or angular distance as a measure of similarity, performs a random sampling, does a single pass over the selected points and then classifies the whole of the scene as described above (CLUS method [4]); the other uses a Euclidean distance weighted with the variance of the classes being formed, processes the whole set of points whilst applying a rejection criterion to the already aggregated points in accordance with the evolution of the classes, and performs several iterations (CLUSW method) [8].

Data Compression: Selection of Linear Channel Combinations

The aim is to construct linear transformations of the measurement space which will reduce the dimension and yet detract as little as possible from the performances of the classification algorithms; this will save computing time and facilitate data handling and storage.

Criterion of Minimum Loss of Information from the Standpoint of Data Variance: Karhunen-Loève Factorial Analysis

In this method the variance of data is represented by the covariance matrix Σ and the transformation is the matrix ϕ^T in which ϕ is the matrix of the eigenvectors of Σ. The channel values become independent in the transformation and the transformed covariance matrix is the diagonal matrix $\Lambda = \begin{pmatrix} \lambda_1 & & 0 \\ & \ddots & \\ 0 & & \lambda_n \end{pmatrix}$ of the eigenvalues λ_i of Σ. If we then choose as the transformation matrix F the first m rows of the matrix n.n ϕ^T (where $m < n$) this means that we represent a n-dimensional vector $\underline{X}$ by a m-dimensional vector $\underline{Y} = F\underline{X}$ on the basis of the criterion of the least mean-square error equal to

$$\sum_{i=m+1}^{n} \lambda_i \qquad \text{(ref.[5])}$$

The data variance fraction retained in the transformation is

$$\sum_{i=1}^{m} \lambda_i \Big/ \sum_{i=1}^{n} \lambda_i$$

Σ can be estimated overall in the scene or calculated by the weighted sum of the covariance matrices Σ_i of the classes of interest C_i estimated over the respective reference zones, as matrix W in the next section.

Criterion of Maximum Separation between Classes: Canonical Analysis

The method employed here uses a matrix of covariance inside the classes, W, which is defined by

$$W = \sum_{i=1}^{h} \frac{N_i - 1}{N - h} \Sigma_i$$

where N_i is the number of elements (vectors) in the reference zone of class C_i, $N = \sum_{i=1}^{h} N_i$ and h is the number of classes, and a dispersion matrix P which is a function of the Euclidean distance between the mean vectors $\underline{M}_i$ of the classes C_i and is defined by

$$P = \sum_{i=1}^{h} \frac{N_i}{\sum_{i=1}^{h} N_i} (\underline{M}_i - \underline{M})(\underline{M}_i - \underline{M})^T$$

where

$$\underline{M} = \sum_{i=1}^{h} \frac{N_i}{N} \underline{M}_i \qquad \text{(Ref. 2)}$$

The criterion of maximum separability between classes leads us to determine a transformation matrix C such that the transform of P, CPC^T will be maximum with the additional constraint $CWC^T = I$ which ensures uniqueness of C and also independence and unity variance of the transformed variables [6,7]. This problem is reduced to a classical problem of eigenvalues: find F such that FVF^T is maximized under the condition $FF^T = I$, with $F = CW^{1/2}$ and $V = W^{-1/2}P(W^{-1/2})^T$; $W^{1/2}$ being defined by $(W^{1/2})^T W^{1/2} = W$ and calculated by $W^{-1/2} = A \Lambda^{-1/2}$ where A is the matrix of the eigenvectors of W and Λ is the matrix of the eigenvalues. The transformation sought is then $C = FW^{-1/2}$. It is a m.n matrix with $m \leqslant n$ and $m \leqslant h - 1$. If we take the first m rows of C, the data variance fraction retained in the transformation is equal to

$$\sum_{i=1}^{m} \lambda_i \Big/ \sum_{i=1}^{n} \lambda_i \quad *)$$

where the λ_i are the eigenvalues of matrix V. The consequence of choosing the maximum separability criterion will be seen in the fact that the linear transformations defined by the successive C rows (i.e. the successive axes of the transformed space that are taken into account) operate a decreasing class-separation from the first to the last row, in terms of classification.

Results Outlined

These preliminary results concern two scenes from LANDSAT-1, one of 10 May 1973 and the other of 7 October 1972, concerning one of the Italian AGRESTE test sites which lies north of the Po between two of its confluents, the Ticino (at the Pavia Level) and the Sesia. This region includes, in particular, the towns of Pavia, Novara, Vercelli and, north of the Ticino, Milan. The initial object of the study was to sound out the performances of the classification methods for the purposes of an inventory of the acreages under rice, which are very extensive in the triangle bounded by the Po and the Ticino, and of the poplar groves, mainly grouped along the Po. What is required, therefore, is not so much the "land use" type of integral classification of a given region into very large classes, but rather a selective classification into specific classes.

Inventory of Rice Acreages

The LANDSAT-1 scene of 10 May 1973 concerns the rice-field zone at the moment when these fields are flooded, and it was found under these conditions that the simplest and most rewarding method of discriminating the rice-fields is a simple level-slicing of LANDSAT channel 7 (near-infrared) where water is assigned the lowest class of values. By this process streams and the roofs in large towns (Milan or Pavia for instance) are classed in with the rice-fields, but it is easy to deduct them from the overall result by processing the same scene again at a time when the rice-fields are no longer (or not yet) flooded, or by a more elaborate treatment involving all four of the LANDSAT channels.

Table 1 shows the results of classification by different methods and the computing times (CPU) with an IBM 370/165 (central memory 1000 K bytes), for a typical zone of about 50 km^2, compared with the evaluation done on the ground for the same zone.

The reference map (Fig. 1), where the rice-fields are shown as black, was made by grouping together the 1/6000 scale survey maps of a number of rice-growing communes updated to 1973 as regards rice by the Italian Ente Nazionale Risi. The evaluation of the area percentages on the map thus formed was done by counting points on an overlay grid (44,000 points counted). The evaluation error should thus be less then 2 per cent.

The calculations using the Euclidean distance between the mean vectors of the classes showed high sensitivity in the results at the threshold chosen for the "water" class; this makes it a tricky method to use in a selective classification context. With the non-parametric linear method it was necessary to define two other fairly large classes as well as "water" – "high vegetation" (trees) and "low vegetation" (fields and meadows) – which were not linearly separable,

*) *This variance is an overall measure of the separation between the classes represented by their mean vectors.*

Table 1 : Percentage of land under rice. Comparison of results obtained with the different methods

Method	% of points classed as "rice"	Difference from reference, in %	% of these points wrongly classed as "rice"	Computing time for 11160 points (sec)
Level-slicing on channel 7 (I.R.)	39.6	– 2,8	< 1	5
Mean vector (Euclidean distance)	38.5	– 5.5	< 1	5
Non-parametric linear classification	34.9	–14.3	< 1	7
Unsupervised classification (CLUS)	34.8	–14.6	< 1	11
Maximum likelihood	31.9	–21.7	< 1	35
Channel 7 / channel 5	43.7	+ 7.3	13.6	–
Reference value	40.73	–	–	–

Fig. 1 : Distribution of rice-fields (black) in the reference zone studied

and we used the technique described in par. "Non-parametric linear discrimination functions" for such cases. Actually the CLUS aggregating technique identified five classes of water in the rice-fields; this fact illustrates the wide dispersion and irregular distribution of the comprehensive "water" class, likewise the relatively poor performance of the maximum-likelihood method in cases of excessively irregular distribution. The performance of the method of level-slicing on channel ratios is also poor, considering the high percentage of wrongly-classed points.

Figs. 1 and 2 show, respectively, the rice-field distribution in the zone studied and the best classification obtained, photographically worked up by an Optronics installation from results stored in magnetic tape. It should be noted that we were able to establish an almost perfect match between the limits of the studied zone on the reference map and the corresponding limits on the classified map, with an error of certainly less than 2% on the areas. The distortion in Fig. 2 is due to a further processing done after the classification in order to correct the well-known geometric deformation of LANDSAT data (on magnetic tapes at all events). These two comments apply equally to what follows. Corrections were also made to the value given by the reference map to take account, first, of flooded meadows, and secondly of rice-fields not yet flooded on 10 May 1973. Examples of these two effects can be seen if the two documents are compared.

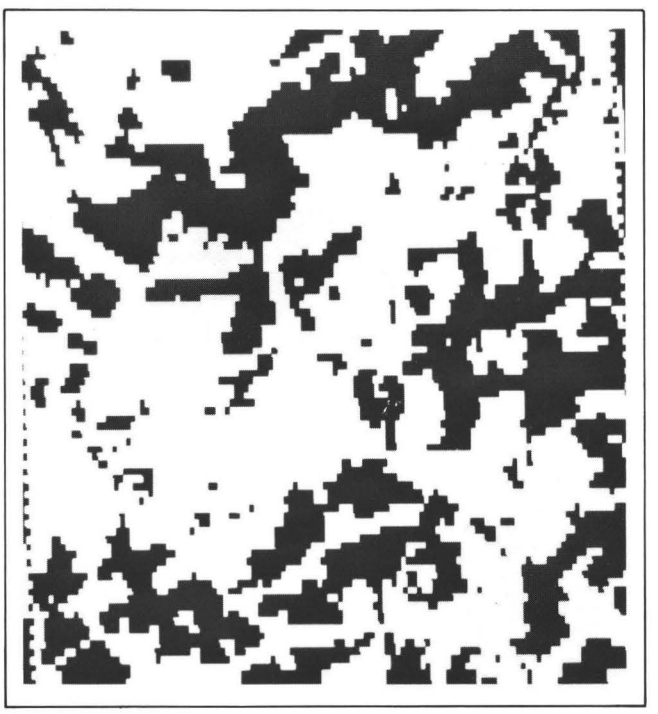

Fig. 2 : Classification of rice-fields (shown in black) in the same zone by level slicing on channel 7 (near-infrared)

Inventory of Poplar-Grove Acreages

This study used the same LANDSAT scene as before with, as reference document for the poplar distribution, a photo-interpretation by conventional methods of an aerial near-infrared photographic cover, scale about 1/8000, dating from early June 1973, i.e. one month after the LANDSAT-1 passage utilized. The photo-interpretation was done by the Italian Istituto Sperimentale per la Pioppicoltura, on a zone of about 30 km^2; it concerned the poplar groves distributed along two big bends in the river Po southwest of Pavia and was checked by direct on-the-spot inspection in cases where interpretation was uncertain. The area evaluation, done by the same method as in par. "Inventory of rice acreages", used some 62,000 points and, besides the poplar groves, dealt with the rice-fields and streams in the zone, the river Po and its tributary the Terdoppio, and the natural wooded areas comprising mainly poplar and willow. The research workers at the Istituto Sperimentale per la Pioppicoltura grouped the poplar groves into three classes by percentage of ground coverage (poplar groves "viewed" from a point situated vertically above them):

- *adult* groves (age $\geqslant$ 7 years) with over 75% ground coverage;
- *intermediate* groves (age 4-6 years) with 25-75% ground coverage;
- *young* groves (age $<$ 3 years) with less than 25% ground coverage.

They estimate the interpreting error to be about 1 to 2% of the grove area.

Fig. 3 is a black-and-white reduction of the original coloured document. It shows the river Po with its two bends, its blind creeks, its tributary that winds along in the upper half, and the rice-fields on the left bank (the Po flowing from west to east). The adult poplar groves are shown in black, the intermediate groves are edged with black lines. The young groves are also shown, in dark grey, but the present status of the study did not allow of identifying them by any method, because the spectral signature of the bare portion of ground varies extremely from one grove to another since it is customary to grow a wide variety of secondary crops in the young groves. The results of classification of rice-fields, rivers and poplar groves are given in Table 2.

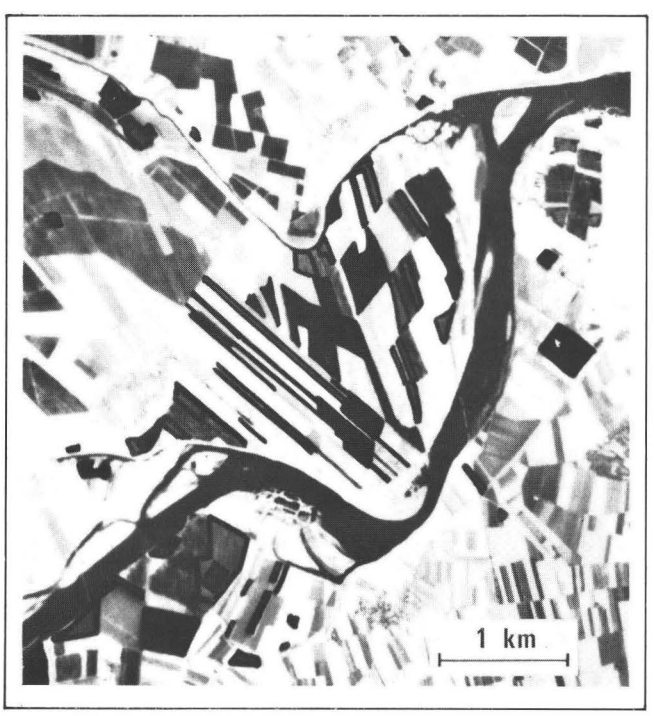

Fig. 3: Reference zone for inventory of poplar grove acreages. The adult groves are surrounded by a black line

Fig. 4: Result of classification by maximum likelihood
Black: streams
Dark grey: rice-fields
Light grey: poplar groves

The maximumlikelihood method, which on the whole gives the best results, actually used for the three classes statistical parameters estimated on samples scattered over a wide area of the AGRESTE test site between the Po and the Ticino; it also used two very broad auxiliary classes, with wide variance, into which were grouped those points in the zone that were of no interest to the study – fields, meadows, villages etc. The non-parametric methods on the other hand used learning samples, taken in the zone under study, for the three classes and for an additional wide-variance class. The methods as a whole demonstrate that it is difficult to discriminate between streams and flooded rice-fields; shallow edges of streams, in particular, tend to be classed as rice-fields.

As to recognition of poplar groves one can see from Fig. 4, which shows the result of the maximum likelihood method, that the big adult or intermediate groves are successfully located, whereas the long narrow groves (average width 25 m) are very hard to detect, owing to the average resolution of LANDSAT. The adult groves lying east of the Po near the edge of the photograph were in fact

Table 2 : Different classification methods applied to rice-fields, streams and poplar groves. Comparison of results

Method	Rice-fields		Streams		Poplar groves		Computing time for 6248 points (sec)
	% of points classed as "rice"	% of these points wrongly classed	% of points classed as "streams"	% of these points wrongly classed	% of points classed as "poplar"	% of these points wrongly classed	
Max. likelihood	10.9	27	8.0	15	7.5	21	18
Mean vector (Eucl. distance)	–	–	–	–	8.0	20	4
Non-parametric linear classif.	13.5	35	8.0	15	12.4	45	4
Non-parametric quadratic classif.	11.8	27	8.4	18	8.1	31	9
Unsupervised classif. (CLUSW)	8.4	33	3.7	2	4.0	6	77
Reference value	10.3	–	8.6	–	adults : 6.3 intermed. : 2.0		–

recognised but were subsequently cut out during the geometrical rectification process. The percentage of points wrongly classed as "poplar" is equivalent to 1.6% of the area of the region studied and corresponds to the evaluation of natural forest zones done by the Istituto Sperimentale per la Pioppicoltura. The overall practical result is that 70% of all the adult and intermediate poplars were recognised.

The CLUSW unsupervised classification method proved good at locating classes, although the percentages found are insufficient. Non-parametric quadratic classification gives results very close to those given by maximum likelihood. The method using channel ratios is not included in the table because, although on the whole it does locate the zones with poplars, it is affected by quite a wide dispersion of the results.

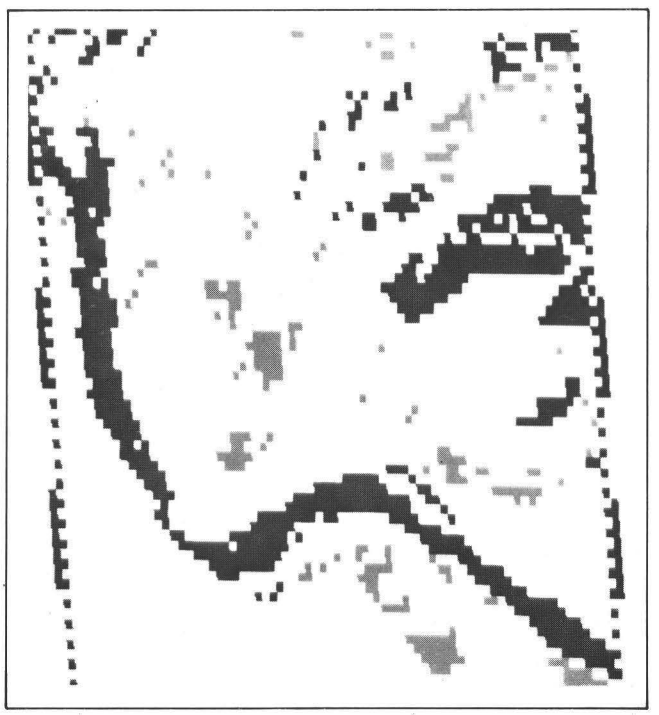

Fig. 5 : Result of unsupervised classification by CLUSW method
Black: streams
Dark grey: rice-fields
Light grey: poplar groves

Fig. 6 : Poplar groves along the river Sesia. Reference photo-interpretation. Adult groves in black, intermediate groves out lined in black; the three zones marked by a central dot in the biggest grove are treeless. The dark-grey areas are rice-fields

Another study that we may briefly mention here, done in an easier context, gave results which were slightly better though erring on the high side this time. For this study we used the LANDSAT-1 scene of 7 October 1972 and, as reference, a photo-interpretation of poplar groves as they stood in 1972 on part of the course of the river Sesia before it joins the Po. The comparison, which concerned the zone defined by the irregular quadrilateral drawn on Fig. 6, used maximum-likelihood classification. The statistical parameters of the classes "poplar groves", "streams" and other auxiliary classes were estimated outside the study zone. The overall results were as follows (Fig. 7):

- estimate of areas of adult or intermediate poplar groves: 25-28%;
- classification by maximum likelihood: 32% of the points, i.e. an excess of about 20%, which may in part be due to possible imprecisions in the interpretation done by correcting a June 1973 document. According to the experts there is a probability that some unidentified adult groves, cut down between October 1972 and May 1973, were not put back into the photograph.

Fig. 7 : Result of maximum-likelihood classification.
Black: stream
Dark grey: poplar groves

Fig. 8 : Result of linear selection of two dimensions out of four by factorial analysis followed by classification by maximum likelihood

Linear Selection of Channels by Factorial and Canonical Analysis

The results obtained by factorial and canonical analysis, for the same zone as that studied in par. "Inventory of Poplar-Grove Acreages" (and using the same classes defined by the same statistical parameters) are summarized in Table 3.

Table 3 gives only the overall results of classification, excluding the percentages of wrongly classed points, which were of the same order as those in Table 2 except in the case of selection of a single axis for the poplar class, and for the stream class in one case. On average, channel selection by either method conserves the same classification results. Overall, the two methods appear to be equivalent, factorial analysis is not very sensitive to the choice of covariance matrix (overall or weighted) except in one case, but canonical analysis, coupled with a classifier using Euclidean distance between mean vectors, displays considerably less tendency to degrade the results when the dimensionality goes from four to one. This, of course, is the consequence of the selection criterion adopted. Fig. 8 illustrates the result recorded in the second row of Table 3, Fig. 9 shows the results of classification by Euclidean distance between mean vectors done after canonical analysis keeping the dimensionality; it is perhaps the best result obtained from the standpoint of class separation with the shortest computing time. Fig. 10 shows the degradation of results with this method when the dimensionality is reduced from 4 to 1 — though this degradation is substantially less than with the other methods.

Table 3 : Effects of linear channel selection on classification results (FA=factorial analysis ; CA=canonical analysis)

Method (CA or FA)	Selection of axes	% of variance retained	% of points classed as			Computing time for 6248 points (sec)
			rice-fields	streams	poplar groves	
Max. likelihood see table 2	–	–	10.9	8.0	7.5	18
FA, overall Σ + max. likelihood	4 → 2	99.3	11.3	7.9	8.4	11
FA, overall Σ + max. likelihood	4 → 1	60.6	12.1	7.2	23.7	8
FA, weighted Σ + max. likelihood	4 → 2	98.4	11.2	7.9	8.4	11
FA, weighted Σ + max. likelihood	4 → 1	78.2	13.1	28.5	23.5	9
CA + max. likelihood	4 → 2	98.0 (matrix V)	11.6	7.9	7.8	11
CA + max. likelihood	4 → 1	93.6 (matrix V)	12.3	7.3	23.4	9
CA + Eucl. distance	4 → 4	98.0 (matrix V)	11.6	7.3	8.9	6
CA + Eucl. distance	4 → 1	93.6 (matrix V)	12.2	8.0	18.6	4
Reference value	–	–	10.3	8.6	6.3 +2.0	–

Conclusions

Our investigation of the commonly used classification methods applied to data from the LANDSAT-1 satellite enabled us to evaluate precisely the percentages of rice-field areas. The evaluation of poplar-grove areas proved to be more difficult under the European conditions of fairly small plantations; nevertheless the average recognition of at least 70% of groves with a ground coverage of over 25% is an encouraging result for purposes of inventory and evaluating amounts of timber. In this context, fairly simple unsupervised classification techniques merit attention. Lastly, the statistical conformation of the LANDSAT-1 data, which were analysed over a small but quite typical zone, suggests that we may well be able to operate a selection of linear combinations of channels with a view to shortening computing times and reducing data handling and storage problems.

Fig. 9 : Result of classification by mean vectors (Euclidian distance) performed after a canonical analysis that did not affect the dimensionality

Fig. 10 : Result of linear selection of one dimension out of four by canonical analysis followed by classification by mean vectors (Euclidian distance)

References

1) R. CASSINIS, S. GALLI de PARATESI, M. GUYADER, Agricultural Resources Investigations in Northern Italy, Southern France and Madagascar, Symp. on European Earth Resources Satellite Experiments, Frascati (Italy), Jan. 28 - Feb. 1, 1974

2) F.Y. BORDEN, D.N. APPLEGATE, B.J. TURNER, H.M. LACHOWSKI, B.F. MEREMBECK, J.R. HOOSTY, Satellite and Aircraft Multispectral Scanner Digital Data Users Manual, ORSER-SSEC Technical Report 1.75 (1975) Office for Remote Sensing of Earth Resources. The Pennsylvania State University

3) N.J. NILSSON, Learning Machines (1965), MacGraw Hill, New York

4) B.J. TURNER, Cluster Analysis of Multispectral Scanner Remote Sensor Data, *Remote Sensing on Earth Resources,* **1,** Ed. by F. Shahrokhi, The University of Tennessee, Tullahoma, Tenn. (1972)

5) K. Fukunaga, Introduction to Statistical Pattern Recognition, Academic Press, New York (1972)

6) H.L. SEAL, Multivariate Statistical Analysis for Biologists, Methuen and Co, Ltd., London (1964)

7) H.M. LACHOWSKI, Canonical Analysis Applied to the Interpretation of Multispectral Data, M.S. Thesis, Pennsylvania State University (1973)

8) W. MEHL, to be published shortly.

Introduction to Engineering Sciences

Department B

S. Finzi

In the reorganized structure of the Ispra Establishment, the following divisions:

- Heat Transfer and Fluid Mechanics
- Applied Mechanics
- Process Engineering
- Electronics
- ESSOR
- Design and Fabrication

formed the Department B.

The fields of competence covered by this Department are clear from the titles of the various divisions, known collectively as "ENGINEERING SCIENCES".

A small group of biologists, who are members of the Ispra Staff but attached to the Biology Division of the DG XII, belongs also to this Department. They contribute to the Environment Programme in the field of eutrophication of lakes and consequences of water pollution.

The contribution of the Engineering Sciences department to the different programmes assigned to the Ispra Establishment is roughly the following:

– Safety	90%
– Hydrogen thermodynamic	40%
– Remote sensing and Earth Ressources	90%
– Solar energy	50%
– Protection of environment	20%
– BCR	25%
– Safeguards	20%
– Fusion	
– Materials	

Continuous support is also given to all the activities of scientific divisions, by the Workshop and Design Office on the one side and by a part of the Electronics Division on the other, in terms of mechanical design and construction and electronic instrumentation.

The ESSOR Division is responsible for operating the ESSOR complex (including the reactor, the attached facilities and the hot labs). Under the agreement signed by the Commission and the Italian Government in virtue of article 6 of the Treaty of Rome, ESSOR has the task of executing the programme financed by the Italian Government on LWR fuel behaviour.

The main achievements of the different divisions during these two years were:

Heat Transfer and Fluid Mechanics

The activities were essentially developed in the following areas, related to the Safety and Solar Energy Programmes:

Nuclear Reactor Core Thermohydraulics

The HERA computer code treating Fast Breeder Safety problems was applied to study the decay of coolant temperature perturbations downstream of a failure zone in a subassembly. This work has shown that even relatively small blockages give rise to an anomalous time-average temperature distribution at the bundle outlet. Preliminary measurements were made of thermal noise and time-average temperature fields in the plenum of an 8-rod linear bundle.

A new fast method was developed for computing transient fuel-rod temperature fields. The development of methods allowing the theoretical prediction of 3-dimensional velocity fields in bundles was started. The studies on emergency core cooling were continued. An experimental facility was set up for studying quenching effects. In the context of contractual collaboration between Euratom, CNEN and BMFT the subject of boiling mixing in 16-rod clusters is being studied.

Depressurization and Blowdown

Most of this work is now done under a four-year R&D contract concluded in December 1973 between the Federal Minister for Research and Technology of the Federal Republic of Germany at Bonn (BMFT–Bonn) and the Commission of the European Community. The work is concerned with the construction of a rather large blow-down loop system and the performance of a certain number of loss-of-coolant experiments defined by the BMFT–Bonn (programme A). After that a similar experimental programme B defined by experiments of all the member countries of the Community will be performed on the same and/or a more or less modified test rig.

The experiments to be carried out with this two-loop system, which simulates the four-loop primary cooling system of a 1300 MWe PWR, are concerned with the investigation of LPWR-LOCA's caused by tube rupture at different positions in the primary cooling system of the reactor, taking into account the intervention of different emergency core cooling systems. The results will be used for checking and improving blowdown computer codes and associated theories for safety analysis of LPWRs.

After a phase of execution of the detailed project of the loop, the main orders were placed and the loop is now being installed. A paper on this activity is included among the Selected Topics in this report.

Liquid Metal Activity

Research on the thermohydraulics of liquid metals was essentially devoted to the investigation of factors influencing the incipient superheat and the transient following the inception of boiling. Systematic studies were performed to find out the importance of various chemical treatments of heating surfaces and the degree of turbulence in forced convection flow on the amount of superheat.

Detailed studies were executed, and terminated as regards the experimental part of modelling the transient flow pattern in a fast reactor geometry following boiling inception, to measure the influence of spacers on the liquid film left on the wall upstream and downstream of a spacer. A further subject of activity was the search for instrumentation methods for the detection of small quantities of gas in flowing sodium. In collaboration with the UKAEA Risley Laboratory, an acoustic Doppler method and ultrasonic travelling time measurement method were tested.

Thermal Applications of Solar Energy

Work is centered on the design and development of high-performance solar collectors with an efficiency of 50% in the range of 100°C. Different solutions are under study, using selective surfaces, or anti-radiation systems such as the FRANCIA system, or vacuum, to reduce heat losses by radiation and natural convection. These collectors are being developed mainly for housing applications in the field of combined heating and cooling, for which a bromide lithium absorption cycle will be tested.
This activity is being carried out in close collaboration with various firms and institutes, such as the CEA for whom experiments are being performed on several test installations including a solar simulator.

Applied Mechanics

The Division's activities essentially come under the head of support to the Commission in connection with the programmes on Safety, Information Analysis Centres and Systems studies for fusion reactors.

Safety

In the field of Fracture Mechanics, the experimental work concerning the behaviour and the significance of cracks was pursued, with the accent on austenitic stainless steels for LMFBR application. A project concerning the significance of toughness degradation due to thermal aging was completed. The results of this project, pursued under a cooperation contract with Interatom (Germany), are summarized in a "selected topic" of this report. Fatigue crack growth tests in sodium environment have been successfully conducted. In cooperation with CEA (France) a project was started to evaluate radiation-induced embrittlement of materials for LMFBR and LWR applications.

The activities to determine the constitutive relations between stress, strain and strain-rate of steels and equations of state of concrete were pursued, with a view to providing input data for the analysis of LMFBR core deformation problems related to hypothetical D.B.A. In cooperation with Belgonucléaire, CNEN and UKAEA various steels for LMFBR applications were tested by means of Hopkinson's bar type of equipment; they inlcude AISI 304, AISI 304L, AISI 347 and some mild steels in the strain-rate range of 10^{-2} to 10^{3} sec^{-1} at RT and in some cases up to 500°C. Hydropneumatic devices able to perform tests at the lower strain-rates ($0 - 100\ sec^{-1}$) have been developed; these allow of an extension to bi-axial states of stress and deformation rates. For the very

high strain-rate range, over 1000 sec^{-1}, a shock-tube device was converted.

With a view to confirming the validity of computerized mathematical models designed to simulate hypothetical accidents in LMFBR, a research programme called COVA (COde VAlidation) was decided upon, consisting of DBA modelling experiments and fuel coolant interaction experiments. A 50-ton base was constructed in a new bunker, intensive work was done to ensuring reliable calibration of pressure transducers and strain-gauge type measuring devices, and new data-processing equipment was set up, allowing work with 42 channels in a frequency band of 0-160 KHz, after which the series of tests covered by this programme was started in collaboration with UKAEA.

Project-oriented studies were also carried out, including large-scale explosion testing of the vessel Balen SNR and tests to simulate plug loading in a 1/6 model of the PEC reactor using bare charges.

Fuel coolant interaction experiments in the Applied Mechanics division are carried out by dropping hot molten fuel into colder coolant in a tank geometry. (The converse experiments, i.e. dropping coolant onto molten fuel in channel geometry, are done in the Heat Transfer and Fluid Mechanics Division). As regards steel sodium interactions, experiments were performed with steel heated up to 1600° C and sodium temperatures between 400 and 500° C. The UO_2 sodium experiments were continued, varying the mass of UO_2 (2 to 3 kg) and the sodium temperature (350, 400, and 500° C). In all these tests only mild interactions occurred. In cooperation with BMFT this type of experiment is being extended to include LWR fuel coolant interactions. To this end an experimental facility was built and the experiments were started in 1975.

Information Analysis Centres

In the context of ESMIS (European Structural Mechanics Information Service) the 3-b benchmark analyses of current LWR pressure vessel components were continued, in particular on BWR pump nozzles (in cooperation with the DAEX) and PWR nozzles (in cooperation with TUV Stuttgart). The analyses were extended to include hypothetical 3-D corner cracks in nozzles, uaing substructuring techniques.

Fusion

In cooperation with the CNEN group of Frascati and the University of Naples, conceptual design studies were carried out concerning the minimum size of an electromagnetic containment for a fusion process (FINTOR project).

Process Engineering

Activities were developed in the following programmes: Remote Sensing of Earth Resources, Hydrogen Production, Standards and Reference Substances, Reactor Safety, and Materials Science.

The Process Engineering division has been involved mostly in activities which are fairly new at the JRC. This situation has imposed a particular effort to acquire and develop new techniques and to organize new laboratories.

To cope with the emergency needs of the programmes the Division was structured into three main branches:

- process identification and evaluation technologies
- physical technologies and
- chemical technologies

We summarize here their main achievements in terms of techniques or methods acquired or developed.

The work of the process identification and evaluation branch is both experimental (equipment surveillance for operational safety) and theoretical (process modelling and reliability evaluation). The outstanding achievements can be considered the successful introduction of heuristic approaches in flowsheet evaluation and optimization and the use of advanced statistical approaches in high-frequency random noise signature analysis. Details of these techniques as applied to stress wave emission will be found among the Selected Topics in this report.

The physical technologies branch is working mainly on surface physics and on electromagnetic wave (visible and infrared) physics.

In the first of these subjects, experimental facilities for studying surface phenomena for fusion reactors (blistering and gas desorption) were put into operation. In the second, an outstanding competence was developed in radiometric techniques for studies on radiance and spectroreflectance in connection with remote sensing applications.

The chemical technologies branch deployed its main effort in equipping new laboratories, for physicochemical measurement (thermogravimetry and high-temperature viscosimetry) and for development of chemical reactors.

The contribution of the Process Engineering division in terms of results useful for the various programmes can be found in the corresponding programme reports. In particular:

- Earth Resources:
  all the activities, in collaboration with CETIS
- Hydrogen Production:
  Flowsheet Wave Emission and Reliability
- Nuclear Safety:
  Stress Wave Emission and Reliability
- CBR:
  Viscosity and Tribology
- Materials Science:
  Plasma Wall Interaction Studies.

Electronics

The highlights of the different activities performed in the Division are listed in the following.

Secretariat of Specialized Working Party on Research in the Field of Biomedical Engineering (CRM/CREST)

Four conferences of the Working Party, composed of national representatives of the Community countries, were held at Ispra and in Brussels.
Fields of main interest were identified for a programme of dissemination of knowledge and preparation of workshops, summer schools and fellowships.

Electronic Support to the Scientific Programmes

Considerable effort was devoted to the specification of a large and complex data acquisition system (more than 250 signal channels) for the Ispra Blow-Down experiment. By using minicomputers we can today solve problems in a simple way where yesterday the cost was still prohibitive. Consequently the request for interfaces and controllers covers a wide range which includes such demands as:

- a special-purpose processor for mass-spectrometry (PEGASO), (see Selected Topic)
- a sequencer with high reliability for reactor safety experiments (COBAL)
- a controller for automatic evaluation of particle distribution in liquids
- a high-precision measurement system for temperature and viscosity.

Parallel with the hardware development a software group was set up. Since the ratio between hardware and software effort will in the future shift even further towards software, the need for effective support in this field is evident.

The study on the introduction of microprocessor in CAMAC systems has been undertaken. The occasion was given by the development of a mini computer that should control the instrumentation for fissile material determination in fuel elements, through gamma ray spectrometry. The mini computer will be provided with a direct memory access both for the sequential input and for the incremental memory for fast data acquisition.

Protection of the Environment

The construction of the Raman Lidar system for remote sensing of atmospheric pollution measurements was practically completed.

The characteristics of a new compact monochromator for measurement of Raman scattering were defined and the instrument ordered. Preliminary in-field measurements of Mie and Rayleigh scattering were performed.

The software is still being developed, subprograms have already been tested. The assembling program is not yet completed.

IR Absorption

The study on the use of an IR tunable semiconductor device laser made substantial progress. The testing apparatus was completed and equipped with a gas cell for spectroscopic measurements.

Two devices emitting in the 5 μm and 8.5 μm region respectively were tested and their tuning characterisitics examined. Preliminary results of high-resolution spectra of NH_3 and SO_2 lines were obtained.

Biotelemetry and Biomedical Transducers

For the measurement of subacute effects of pollutants in air and water on small laboratory animals, the microminiaturized devices for biosignal transmission were further developed.

A prototype of a small transmitter with long operation time was constructed in thick-film technology and tested, and the receiving equipment was completed.

During animal experiments it was found that even very small identification circuits fixed to the legs of rats are not tolerated by the animals. This problem needs still to be overcome.

Design and Fabrication

The aim of this unit is to give technical and scientific assistance to the research activities carried out by the different laboratories of the Establishment, providing the design and construction of the experimental mechanical and electromechanical devices. The unit relies on:

- a design office
- a main workshop (about 80 people)
- 11 small workshops (about 30 people) attached to the main laboratories in the centre
- a Private Firms section, which is responsible for ordering, supervising and commissioning of work placed with the mechanical and electromechanical firms outside the Centre.

During 74-75 the design office received requests for about 50 studies of various magnitude. The main achievements that deserve mention were: the designing of the new EURACOS experimental device, a neutron converter which had to be removed from the ISPRA–1 Reactor to a TRIGA-type reactor at the University of Pavia; a substantial contribution to the design of the Blowdown loop, the important experiment in the field of thermohydraulics evaluation of LOCA in LWR's which will be carried out by the HTFM Division; irradiation devices for the ESSOR Reactor; an automatic sampling device for polluted air, developed in the context of the Environment Programme research carried out at the Centre. This last device was considered of interest for industrial applications and a licence will be granted to industrial firms.

Furthermore the Design Office produced or commissioned and supervised the production of about 6000 hours for graphs, diagrams and artists' views needed by scientists for conferences and publications. The main workshop, the laboratory workshops and the Private Firms section make pieces of equipment according to the requirements of the Scientific Departments. These requirements vary from major construction jobs to short interventions for maintenance.

In the main workshop about 500 orders of some importance were executed. Work of a certain interest from the standpoint of technology and importance included the following:

- a rig in ESSOR for capsule irradiation and 6 pressure tubes in Zr.Nb alloy;
- a shielding structure for the above-mentioned EURACOS converter;
- a mechanism for the experimental zone of the RB2 reactor at Bologna (Italy) in which a critical experiment was performed by the JRC staff;
- a series of apparatus for safety experiments in fast breeder reactor containment models;
- a vertical scanner for the γ spectroscopy measurements on fuel elements;
- equipment for melted-fuel water interaction experiments, in the field of safety research.

During these years, despite the difficult financial situation, we were able to improve the potentiality of the workshop, and consequently the quality and efficiency of production, through the installation of some special apparatus – a pantographic table with photoelectric reading device, a

large-capacity profile projector, a guiding machine with continuous optical control of intricate forms and a numerically controlled lathe.

A small professional school continued its activities: a dozen students obtained their diplomas. The Private Firms section supervised about 200 orders of varying importance placed with private industrial firms.

ESSOR Division

During 1974 and 1975 the principal activities of ESSOR continued on the basis of the impulse given by the first meeting of the Steering Committee which took place on 20th December 1973. The objectives which were then fixed were the following:

- to complete, if possible before summer 1974, the essential modification of the reactor in order that the irradiations might be launched as soon as the test sections were available;
- following this, to study as soon as possible the most important modifications which would permit of adapting the handling installations to the requirements of the experimental programme;
- to prepare the irradiation devices and the test sections of a complementary or transitional nature in order to start the irradiation programme in September 1974 and to continue it until the middle of 1975;
- to continue the installation of the second channel of the CART circuit;
- to continue the studies regarding the new irradiation circuits as specified in the reference Italian programme.

Modification of the Systems

These modifications were initially the critical point in the intricate complex of work envisaged in order to permit irradiation of test sections of a transitional nature as early as the middle of 1974; they were in fact completed in June. The loading of the reactor and the nuclear test at full power took place as foreseen before the summer of 1974.

During 1975 the hoisting devices of the two loading and unloading machines were changed and a design study for a storage and handling pool inside the containment building, of great importance for the future experimental programme, was undertaken.

Irradiation Devices and Test Sections

Various complementary sections were called for by the experimental programme, as follows:

- the liquid safety rods, which are formed of two groups of 3 rods installed in two channels of the experimental zone. The functional tests were terminated in April 1974 and the circuits were ready for commissioning with demineralized water as soon as power operation of the reactor should begin. The test programme for these rods under irradiation, the study of the neutron transient and the measurement of the real insertion time and of the antireactivity took place according to schedule.
- The Colibri test device, inserted in a Zenon fuel element of the driver zone.
  The Zenon device was built in the Centre workshops and was available in September. The Colibri 1 device, of interest to the DRAGON project, was built by the CEN Saclay, delivered to Ispra at the end of September and introduced into the reactor and irradiated with the 1st cycle of November. After 98.54 irradiation days a helium loss was noted in the external circuit which insulates the capsule. The test was terminated after a second leak was discovered in an internal circuit insulating the capsule, after 132.74 irradiation days. In spite of these technological problems, due to a defect of fabrication, we can conclude that the particle coating gives very satisfactory results since no appreciable activity was detected in the primary circuit.
- The Gioconda device, inserted in one of the sub-channels of the Modeste device in a channel of the experimental zone. The Modeste device was connected to the moderator circuit in December. The Gioconda test, which concerns measurement of the thermal conductivity in a fuel rod, was built by the CEN Grenoble. The test was introduced into the reactor in January and the irradiation continued normally until the shutdown of the reactor in July.

- The irradiation of two specimens of CIRENE–Spiedo structural elements placed in a Zenon device in September 1974 and in January 1975.
  The test concerning the doping of silicon in order to transform a certain part into phosphorus by an n, γ reaction and the utilization of the product for the fabrication of semi-conductors. This is an operation for industrial purposes and is an interesting example of diversification of reactor utilization.
- Irradiation of collectrons and Zenon capsules in the driver zone and reflector, for physics parameters.
- The hydraulic pneumatic Rabbit device, which can be loaded and unloaded with the reactor in operation and is designed for the irradiation of different materials in non-instrumented capsules, was loaded into channel 10 of the experimental zone. It will be used to produce radioelements and for activation analyses for the JRC.

The Second CART Channel

The on-site assembly of the second channel and the modifications effected on the CART circuit were restarted in July 1975. They continued at the accelerated rythm until the end of 1975 and the circuit should be again operational in February 1976.

The New Circuits

The design and fabrication of four major new circuits, provided for in the reference Italian programme were continued in parallel. At the end of 1975 the status of these projects was the following:

- IRA: the study contract which was launched in March 1974 allowed the start of the fabrication stage in September. The difficulties in the supply of the Zircaloy and a substantial increase of the overall cost of the circuit required a reexamination of the situation at the end of 1975.
- The large circuits (Cleopatra and Cabiria): the study contracts were launched in March 1974; with the FIAT and PMN organizations, with which the UKAEA Harwell was associated in September 1974 on the basis of an expert consulting contract. The construction specifications were approved early in 1975. The fabrication dossier and the tender have been received, and the fabrication contracts should be initiated at the beginning of 1976.
- SARA: this contract was given to UKAEA Harwell, which has good experience in the fabrication of this type of circuit. The work originally was concerned with a primary and secondary feasibility analysis and led to several changes in the specifications of the project. The preliminary design study was initiated in September 1975.
- The ESTER project: the specifications for the fabrication of this device were ready in March but the work was held up because of delays in the signing of the contract.
- The reactor, after its reconversion as described above, operated continuously from 6 November 1974 to 7 July 1975.

Experimental Investigation of the Influence of PWR-Loops on Blowdown

W. Riebold *

General Remarks

The LOBI (Loop Blowdown Investigations) Project activities at Ispra are performed mainly under a four-year R&D contract between the BMFT**Bonn and the Commission of the EC. This contract (RS-109/143-73-PIHOD), concluded in December 1973, concerns the construction of a rather large blowdown loop system and the performance of a series of loss-of-coolant experiments which are defined by the BMFT (programme A).

A similar experimental programme (programme B) which is to be defined by experts of the Community countries, will be performed afterwards on the same and/or a more or less modified test rig.

The *objective* of this LOBI Project is the experimental investigation of the role of the different components of a PWR primary cooling circuit during a blowdown by the measurement of the main thermohydraulic quantities, especially those which influence the core cooling, i.e. the flow and heat-transfer conditions and the pressure differences. The experimental results will be applied to check and improve the blowdown codes and associated theories used for the safety analysis of LWR's.

The *scaling conditions* for the test facility design from a 1300 MW(e) PWR reference plant are the following:

- a 4-loop PWR primary cooling system is simulated by a 2-loop experimental system, one loop representing three intact "reactor" loops and the other representing the broken "reactor" loop; both loops are active loops containing pumps and steam generators; tube ruptures of different rupture sizes are to be simulated at three different positions within the broken loop (Fig. 1);
- the scaling factor of 712 for power, mass flow and volume leads to 5 MW heating power input to a 64-heater-rod bundle as reactor core simulator;
- size reduction maintaining the power-to-volume ratio;
- 1 : 1 design (with respect to reactor situation) of

  - pressure drop distribution
  - fluid temperature distribution
  - components volume ratio
  - elevations of the components

  } over whole the loop system

  - lengths of the heat transfer surfaces (core rod bundle, steam generator).

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The project work started in January 1974 with the revision of the preliminary design of the experimental loop system (project phase II according to the planning of the total project).

Description of the 1974 and 1975 Activities

The activities during 1974 and 1975 were mainly concerned with the final designing of the entire experimental test system (including electrical power supply, regulating and control system, measurement instrumentation and data acquisition system) and the placing of orders.

1. Design of the LOBI Test Facility

During the first year of the project work two major modifications were made to the loop system design, which led to much more comprehensive revision work (phase II of the project planning) than previously planned.

In January 1974, the BMFT–Bonn had changed the reference plant for the experimental loop system from a 600 MW(e) to a 1300 MW(e) PWR. Maintaining the heating power input and the number of heater rods, the scaling factor increased from 500 to 712. The reference plant change led to a greater heated length (3.9 m instead of 3.0 m), greater height of the reactor model, greater height of steam generators and higher mass flow rates. Two separate steam generators had to be provided instead of the single one previously planned, in order to avoid thermohydraulic coupling of the two experimental loops by the secondary-circuit water. Design and scaling of the steam generators had to ensure that (a) the ratio between the secondary water volume in the steam generator downcomer and in the core part, and (b) the ratio between the secondary water volume in the core part, and the primary water volume in the U-tubes, are the same as in the reference plant. Finally, the double-ended rupture devices had to be designed in such a way that the pressure and flow conditions upstream of the rupture section were the closest possible to those expected to occur in reality.

In August 1974, information obtained from a discussion between USAEC and BMFT representatives about special thermohydraulic phenomena which occur within the reactor downcomer during blowdown, strongly influencing the time delay for ECC water delivery to the lower plenum, made it appear reasonable to design the experimental downcomer in the same geometrical shape as the real one, i.e. an annulus instead of the previously conceived circular tube. This change led to a significant modification of both the reactor model and the configuration of the tubing system.

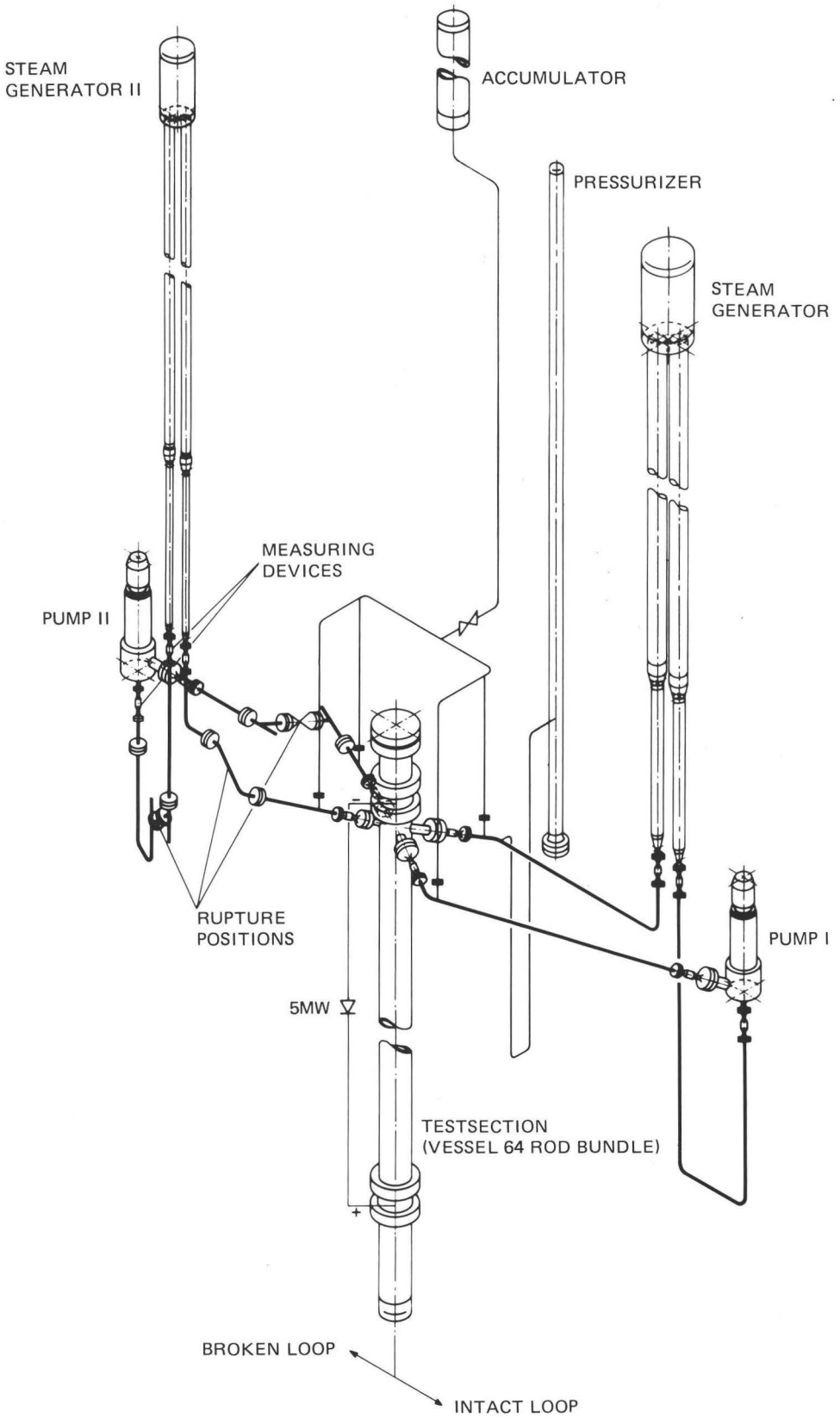


Fig. 1 Blow Down Loop System

Because of all these modifications, the final design and the ordering of the whole loop system has been delayed.

2. Mechanical Loop Components

P. Mörk-Mörkenstein, G. Friz, H. Geist, K.H. Guenther, F. Peters, L. Piplies, R. Rota

In April 1974, the most recent results of the computer-code calculations on pump behaviour during blowdown were made available to us by the German reactor industry (KWU-Erlangen). These results, showing the time history of the pump mass flow, pressure head, speed and torque occurring during blowdown, necessitated fresh technical discussions with the manufacturers in order to revise the specifications for the required pump design performances before inviting new tenders. This, together with rather heavy internal administrative procedures, led to great delay in ordering the pumps, which again lengthened the delivery time. So the pumps, being on the critical path of the project time schedule, have up to now delayed the project by about 10 months.

Three pumps of the same type and size have been ordered; their special performance feature is that the required two different (1 : 3) rated mass flows at the same pressure head are achieved by operating the pumps at two different speeds. Two pumps will be delivered directly to Ispra to be installed into the LOBI loops. The third pump will be delivered to the GKSS–Geesthacht (W. Germany) and used there for investigating the two-phase flow pump characteristics under a separate R&D contract from the BMFT-Bonn. Thereafter the third pump will be available as a spare for the LOBI experiments at Ispra. These two-phase pump characteristics are needed to control the pump speed during a blowdown experiment so that the hydraulic behaviour of the experimental pump will be similar to that of the reactor pump during a reactor blowdown.

All mechanical parts of the LOBI test facility (two primary loops, the secondary loop and the auxiliary systems) were finally ordered in March 1975 and will be delivered to Ispra in March 1976 for mounting.

The reactor model, consisting of the pressure vessel, the core barrel tube and three heater rod bundles, were ordered in May 1975 and will be delivered to Ispra in June 1976 to be assembled and then mounted into the loop system. As the manufacturer constructing the reactor model had special workshop facilities and machining know-how, it was possible to use Inconel 718 as the pressure vessel material. This allowed us to obtain an extremely small wall thickness of 8 mm only, which contributed remarkably to minimizing thermal stresses during blowdown.

Long-term solubility tests with quartz glass and ceramics in water at temperatures up to 270°C indicated that 99.7% Al_2O_3 ceramic is the best insulator and filler material between the heater rod bundle and the core barrel tube.

Thermal shock tests with closed and open annuli of the same material have shown that open annuli could be used for varying the downcomer gap width by slipping them over the core barrel tube. This alternative would strongly reduce the stored heat effect within the downcomer during blowdown; that effect is much bigger with the other alternative using core barrel tubes of different wall thicknesses. The final decision is still to be made and depends also on operation reliability features.

The two "experimental" heater rod bundles (for the blowdown experiments) will each be composed of 64 directly heated stainless steel tubes, with stepwise varying wall thickness to give a cosine-shaped axial heat flux distribution. Each heater rod will be instrumented with three 0.8 mm OD sheathed thermocouples for outer surface temperature measurement during blowdown. The thermocouples are mounted at four sets of axial positions, i.e. 16 rods have their thermocouples at one set of 3 devations, another 16 at another set of 3 elevations, and so forth, giving in all wall-temperature readings at 12 different elevations over the heated length of the rod bundle.

The third or "commissioning" heater rod bundle (for commissioning the loop system) will be composed of 64 directly heated stainless steel tubes with constant wall thickness and 8 instrumented rods for control measurements only.

The tube ruptures will be effected in special inserts installed at three different positions in the tubing of the broken loop. The ruptures themselves will be simulated by fast-opening flaps having an opening time of less than 20 ms.

The rupture inserts will be housed inside concrete bunkers allowing simulation of the containment back-pressure of up to 4 bars which occurs during blowdown.

3. Electrical Power Supply and Loop Controlling Systems

L. Fritz, P. Mörk-Mörkenstein, H. Heiter, H. Hülser

In the LOBI experiment the effect of stored heat release from the reactor fuel rods during blowdown cannot be simulated, owing to the much smaller heat capacity of the hollow heater rods in the experiment. In order to compensate at least to a certain extent for this lack of simulation, it is intended to appropriately control the electrial heat input to the heater tubes during blowdown. The required time function for this heat input was determined by special heater rod calculations with a blowdown code, which were performed by the LRA-Garching. The results from these calculations were used to specify the required power control performances of the 5 MW rectifier system. Furthermore, in order to reduce disturbing pulses coming from the power control system, the power is controlled by switching binary-graded power subgroups.

The final specification of the complete power supply system was achieved only through close contacts with the manufacturer. The order was placed in April 1975 and the delivery will be in July 1976.

After completion of the final design of the loop system, the loop controlling and regulating system was finally specified; this again was only possible through frequent discussion with the supplier. The complete system was ordered in June 1975 and will be delivered by June 1976.

4. Measurement Instrumentation and Data Acquisition System

J. Eder, F. Wind, H. Scheufler, G. Friz, L. Piplies, W. Schulze, G. Weste

The accuracy and reliability of the information to be

obtained from these experiments are strongly dependent on appropriate instrumentation of the experimental loop system and the availability of suitable measuring techniques.

The significant thermohydraulic quantities of these experiments are the fluid temperature, the absolute and differential pressures, the fluid density (void fraction) and the mass flow rate. The measurement of all these quantities will be done at the boundaries of each loop component, where special spool pieces are placed, into which the measuring probes will be installed. Further quantities to be measured during this experiment are the wall temperatures of the heater rods, the wall temperatures of the loop system, and the pump power, speed and torque.

One general requirement to be met by all measuring devices is a rather fast time response, ranging from less than 1 ms for absolute pressure up to about 100 ms for differential pressures. To satisfy this condition the transducers (thermocouples, pressure transducers and other measuring probes) must have appropriate performance characteristics and special attention has to be paid to their installation.

A special pressure transducer with an integrated hydraulic signal transmission column was developed in close cooperation with a manufacturer. Comprehensive tests with different prototypes finally led to the most appropriate design, showing an overall error band of less than 1.5% FS over the whole temperature range from 20 to 350°C. The complete pressure measuring channels have been ordered and will be delivered in January 1976.

For the differential pressure measurements two particular difficulties had to be overcome. First, to prevent the formation of a two-phase mixture inside the signal transmission line between the measuring location and the transducer, a special water-cooled pressure tap adapter has been designed for installation at the measuring location. Secondly, the occurrence of wide pressure differences within the first instants of a blowdown means that the differential pressure transducers must withstand two-directional overloads up to 15 times the measuring range without causing an error increase. Several preliminary tests did not yield satisfactory results; further tests are still under way.

For the fluid and wall temperature measurements special adapters for the thermocouple installation have been designed and tested and are now under construction.

To calibrate the pressure and temperature measuring channels a small autoclave has been constructed and mounted, by which pressure and temperature transients can be produced.

For the mass flow-rate and fluid density measurements at present no sufficiently clear and developed measuring techniques for both quantities are available. The density measurement will be done by γ-ray absorption technique, even though at present the obtained signal reveals a rather broad uncertainty band as regards the fluid density because the signal does not depend on the fluid phase distribution along the detecting ray, whereas the density does, rather strongly. Further development work is necessary, and partially already under way, to improve this method especially with respect to this point. First results from theoretical considerations about multi-beam arrangements showed that a two-beam measuring device represents the best compromise with respect to the equipment effort required and precision to be obtained.

For the two-phase mass flow measurement there are some efforts actually under way in the GfK-Karlsruhe IRE to develop a "true mass flow meter", which allows the direct measurement of the desired quantity but unfortunately causes a rather strong flow disturbance. Any other existing and more or less directly applicable techniques do not directly yield the desired quantity; always two out of three different measurements are needed to determine the mass flow. The two most suitable and mature techniques are that of an average volume-rate or velocity measurement by a turbine flow meter and that of a locally-averaged flow momentum measurement by a drag-disc. It is intended to use both methods together in the LOBI facility.

The use of turbine flow meters is conditioned by two essential difficulties given by a rather limited measuring range and an even more limited lifetime of the bearings. A further restraint is caused in our case by the presence of a strong and time-variable magnetic field. It has therefore been decided to do preliminary tests with one such probe before giving the final specification for the performances required.

For the flow momentum measurement the Battelle-Frankfurt design of drag-body will be used, which is a special development for the LOBI experiment done under a R&D contract from the BMFT-Bonn. A first prototype will be tested in December 1975.

Two further measuring method and device development works are under way since September 1974 under R&D contracts from the BMFT—Bonn, too. They are concerned with the application of the radio tracer technique (LIT of the GfK—Karlsruhe) and with the use of correlation techniques for transit time measurements from temperature noise signals (IKT of the TU Berlin). An experimental feasibility study on the application of nuclear magnetic resonance techniques will be done during 1976, again under a R&D contract from the BMFT—Bonn (RWTH Aachen). Finally, on a joint measuring-methods test facility, now being constructed at the GfK-Karlsruhe IRB under a further R&D contract from the BMFT—Bonn, all these methods will be tested against each other and possibly even calibrated.

It is intended to use also these methods, if successfully developed right in time for being taken into account, for the LOBI experiment.

The signals from the measurement instrumentation will be recorded by a specially tailored data acquisition system. To meet the requirements of the present experiment, namely high data throughput rates and consequently an extensive storage capacity, the whole system is divided into two main sub-systems. The first of them is concerned with the signal processing (digitalization of the analog signals coming from different sources) and the data storage tasks using PCM and FM recording techniques. The second part

consists of two separate process computers; one of them tailored to evaluate conventional experimental data and to control heating power input and pump speed versus time, the other one representing the basic component of a time series analysing system which is needed for the evaluation of the mass flow and density data.

This latter computer also monitors DNB in the heater rod bundle, using as criteria the temperature gradient and a temperature set-point.

The time series analyser was delivered in July 1975 and put at the disposal of the IKT, TU Berlin, which will set up the evaluation programs mentioned above.

The data acquisition system is ordered and will be delivered in April 1976.

5. Theoretical Work

G. Friz, W. Kolar, L. Piplies, W. Brewka

Theoretical work for the Blowdown project was mainly concerned with calculations supporting the loop design and instrumentation work.

Loop tubing and container dimensions were determined by volume and pressure-drop distribution according to simulation requirements. The influence of stored wall-heat release was determined, in order to obtain a criterion for the choice of material to vary the downcomer gap-width.

Special heater rod calculations done by the LRA-Garching yielded the required time function for electrical heat input to the rod bundle during blowdown. Optimization calculations gave the required deviations from exactly binary-graded power subgroups of the 5 MW rectifier system to reach fairly smooth power curves.

Blowdown calculations for the reference reactor were done to obtain information about the required measuring range and time gradients for the different thermohydraulic quantities to be measured and recordered during blowdown.

Theoretical considerations about the influence of velocity and density profiles on the signals from turbine flow meters showed that rather high errors can occur in the volume flow rate determination.

Blowdown calculations with the RELAP4 code with different closing times for the isolating valve between the break branches showed that closing times shorter than 100 ms do not influence blowdown history within the first second.

BERSAFE-code calculations for determining the stress fields in the upper power-connecting plate of the test section (reactor model) due to temperature and mechanical loads showed that shear stresses of 800 kp/cm^2 can occur in the welding layer between the two materials of the sandwich-type plate; these stresses are tolerable.

STRUDL–II code calculations were done to determine the thermal dilatation of the total loop system: the results introduced into an isometric loop representation showed the magnitude and direction of displacements at the different positions.

For the time being, the STRUDL-II program is used to calculate the natural frequencies of the different components of the blowdown loops. The next step will be the determination of the hydraulic forces acting on the different components of the loop during a blowdown.

The device to be used for simulating 2-A breaks will be employed also to simulate the 1-A and smaller breaks. This is possible because theoretical assessments have shown that the influence of asymmetric flow towards the rupture section is negligible.

The ECC injection lines from the accumulators had to be redimensioned in keeping with the scaling laws. This was necessary as a result of adding non-return valves and altering the junctions between the injection lines and the hot legs.

In collaboration with Battelle-Frankfurt the work on the "drag body" development continued. Owing to the limited measurement range three different types are needed, for the broken loop, the intact loop and the lower plenum.

The program REDU4, which allows redimension of all variables in the 64 COMMON blocks of RELAP4, has been completed.

This program allows:

- a "general" redimension of RELAP4 by choosing new values for certain basis variables such as number of volumes, number of junctions, number of pumps etc.,
- a "specified" redimension of a variable within a COMMON block, without changing the dimension of all others,
- the addition of new variables, which may be dimensioned or without dimension.

These possibilities may be chosen all together or in any combination of two of them.

In December 1973 the Advisory Committee for Management of the Safety Programme (ACMP) of the Commission of the EC had charged an ad-hoc working group, composed of experts of the member countries of the Community, to set up an experimental programme (programme B) which will be performed for the Commission with the same test rig when programme A has been completed for the BMFT–Bonn.

Proposals for such a programme had been elaborated by the project group and submitted to the ad-hoc working group for their views. They have agreed to the execution of programme B in two main steps:

a) about seven reference tests (repetition of tests of programme A) which at the same time constitute reproducibility tests;
b) components studies, to be done with this test rig after having modified certain components; the purpose of these tests is to investigate the influence of the geometrical shape or the elevation of these components on the blowdown.

Seven such modifications of the programme A test rig have been agreed upon:

- variation of the depth of the loop seal (U-tube between steam generator and pump) in the intact loop,
- variation of the steam generator elevation in the intact loop,
- variation of the volume of the lower plenum (higher l/d ratio),

- two separate accumulators, one for each loop, instead of one accumulator for both loops,
- simulation of a primary tube rupture within the steam generator (of the broken loop),
- simulation of a small rupture within the lower plenum,
- ECC water injection directly into the upper plenum.

The costing of these modifications was done on the basis of feasibility studies. The necessary funds from the Commission's budget, allocated to the project budget in the beginning of 1975, enabled orders to be placed for these modifications and for all the mechanical loop components.

6. Planning

The time schedule of the entire project, according to the plan made during preparation of the tender for the BMFT-Bonn, is as follows:

Project Phase I: elaboration of the preliminary project and of the tender to the BMFT–Bonn for performance of this project at the JRC Ispra: November 1972 – April 1973.

Project Phase II: revision of the preliminary project: ask suppliers for confirmation of existing tenders and invite new tenders; place orders: January 1974 – September 1974, meanwhile extended up to beginning of 1976 for material with short delivery time.

Project Phase III: construction and mounting of the test facility; preparation of computer programs for process control, data acquisition and evaluation; prototype testing and construction of facilities for calibrating measuring devices; blowdown code design and pre-prediction calculations: October 1974 – December 1975, meanwhile extended to November 1976.

Project Phase IV-1: commissioning of the whole test facility and performance of preliminary tests; pre-prediction calculations, preparation of evaluation programs: January 1976 – December 1976, meanwhile postponed to November 1976 – October 1977.

Project Phase IV-2: performance of programme A test (BMFT–Bonn); pre-prediction calculations and evaluations: January 1977 – December 1977, meanwhile postponed to November 1977 – October 1978.

Project Phase V: performance of programme B tests (CEC); pre-prediction calculations and evaluations: January 1978 – December 1978, meanwhile postponed to November 1978 – October 1979.

References*

1) Tender to the BMFT–Bonn for the execution of the project "Experimental Investigation of the Influence of PWR-Loops on Blowdown" at the EURATOM JRC, Ispra, elaborated by the Technology Division of the JRC, May 1973
2) I. Quarterly Report 1974, IRS–F–20 (July 1974)
3) II. Quarterly Report 1974, IRS–F–21
4) III. Quarterly Report 1974, IRS–F–22 (December 1974)
5) IV. Quarterly Report 1974, IRS–F–23
6) Annual Report 1974, IRS–F–24 (May 1975)
7) I. Quarterly Report 1975, IRS–F–25 (May 1975)
8) II. Quarterly Report 1975, IRS–F–26 (August 1975)
9) III. Quarterly Report 1975, IRS–F –27 (December 1975)

* *All references mentioned are available from the IRS-Köln, Glockengasse 2 (Federal Republic of Germany) subject to permission from the Bundesminister für Forschung und Technologie of the Federal Republic of Germany*

A Fracture Mechanics Evaluation of the Toughness Degradation of Austenitic Stainless Steel Due to Temperature Aging

B. Henry

Introduction

The safety evaluation of LMFBR requires the demonstration that environmental degradation of the structural material properties will remain tolerable and this demonstration has to be expressed in terms having an engineering significance. This problem has arisen in regard to the fracture-toughness degradation of austenitic steel due to long-term temperature aging at LMFBR temperature. The experimental work described herein was undertaken to obtain precise data concerning this phenomenon and more generally to develop a materials evaluation method based on fracture mechanics which could be of help for other such problems (irradiation embrittlement, in-pile surveillance).

When brought to temperatures higher than 500°C, austenitic stainless steels are known to suffer precipitation of brittle phases, like carbides and intermetallic compounds — the best known among them being the sigma phase — which causes a decrease of the ductility. For a given aging temperature and duration, the intensity of this effect depends on the steel composition (for instance it is more significant in molybdenum-containing grades, and their welds) and on the testing procedure used to characterize the loss of ductility: one of the most sensitive parameters seems to be the absorbed energy in impact testing, whereas deformation characteristics under tensile tests of short or long duration are far less influenced.

Precisely for that reason, characterization methods based on fracture mechanics appeared to be of interest here beacuse, within the present limits of their theoretical development, the measured parameter enables one to establish a practical relationship between the load and the maximum tolerable defect length in a given structure; thus the material degradation can be judged in terms of engineering safety. It must be stressed, however, that linear elastic fracture mechanics (LEFM) cannot be applied in practice to LMFBR structures (high toughness, low thickness) and that approaches able to cope with a large degree of yielding at failure have not reached the same degree of development and acceptance as LEFM.

A very concise summary of the basis of two such approaches, the C.O.D. approach and the J-integral approach, which are used in the present work, is given in the following section.

General Yielding Fracture Mechanics Theories

The Crack Opening Displacement Approach

Plasticity at a crack tip leads to a separation of the crack flanks even at the very end of the crack. This quantity called "crack opening displacement" (δ : Fig. 1)

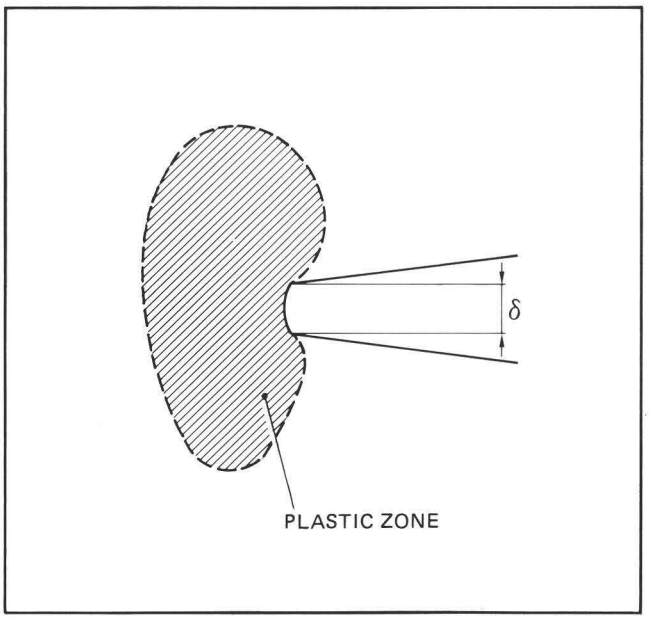


Fig. 1 Definition of C.O.D.

was proposed ten years ago by Wells [1] as a fracture criterion for the situations where plasticity develops significantly before fracture. According to this criterion, crack instability is reached when the C.O.D. reaches a critical value, δ_c, a material constant under certain conditions.

Well below general yield, the C.O.D. is closely related to the linear elastic parameters K — the stress intensity factor — and G — the strain energy release rate, provided that both the latter are corrected for local plasticity. The following relations hold for the current values of these parameters and their critical values (at crack instability):

$$\delta = \frac{G}{n\sigma_Y} = \frac{(1-\nu'^2)K^2}{nE\sigma_Y} \qquad (1)$$

where E is Young's modulus, σ_Y is the material yield strength, ν' is the Poisson coefficient in plane strain and is 0 in plane stress, and n is a contraint factor (approximately 2 in plane strain and 1 in plane stress). The validity of the approach can, however, be extended to the cases where the linear elastic parameters loose their significance owing to large-scale yielding, up to and including situations of gross plasticity.

For the application to a practical structure, one needs (a) to know the critical C.O.D. in environmental conditions

relevant to the structure and under the same conditions of "constraint" or triaxiality at the crack tip: this requires testing on a specimen of thickness equal to that of the structure. A tentative British standard of the measurement method is available [2]; and (b) to know the "design relationship" between C.O.D., load, defect dimensions and bulk geometry. The corresponding analytical methods have not been developed to the same degree as linear elastic K calculation methods, but 2D finite-element elasto-plastic methods have been used successfully, at least in the case of simple specimen geometry and loading, e.g. [3].

A practical guide for the use of the approach has been proposed in [4]: the tolerable defect dimension α_c is given in terms of:

$$\alpha_c = \text{constant} \times \frac{\delta c}{\sigma_Y / E}$$

where the constant is tabulated vs. the ratio of the working stress to the yield stress (or working strain to yield strain).

The J-integral Approach

The J-integral is defined [5] for a crack in a bi-dimensional stress/strain field by:

$$J = \int_{\Gamma} W\,dy - \vec{T} \cdot \frac{\partial \vec{u}}{\partial x}\,ds \qquad (2)$$

where $W = \int_0 \sigma_{ij} \cdot d\epsilon_{ij}$ = strain energy density

Γ : any contour surrounding the crack tip

$\vec{u}$: displacement vector

$\vec{T}$: stress vector on the element ds of the contour: if $\vec{n}$ is the normal vector to the contour, the components of $\vec{T}$ are:

$T_i = \Sigma\, \sigma_{ij} \cdot n_j \qquad (i, j = x, y)$

The following properties of J have been demonstrated:

a) it is independent of the chosen countour Γ for elastic (linear or not linear) and in practice also for real plastic materials when loaded monotonically [16].

b) $J = -\frac{1}{B} \cdot \frac{\partial U}{\partial a}$, U being the total potential energy of the monotonically loaded body [5].

Note that for elastic (linear or not linear) materials only, this expression may be related to the energy available for crack extension and has exactly the same meaning as the strain energy release rate G.

c) J characterizes the stress-strain field singularity, at least for monotonically loaded bodies [17].

d) The J-integral and C.O.D. parameters are linearly related, by a relationship of the form [3, 16].

$$J = M\sigma_y \delta \qquad (3)$$

where M depends on the structure configuration ($1 \sim < M \sim < 2$).

Properties a and c are the basis for J to be a fracture criterion under large-scale yielding conditions, at least for crack initiation, while property b provides a basis for an easy experimental determination [6] or finite-element computation [3, 6] of J.

The use of J as a fracture criterion will be based on:

$$J = J_c$$

How far J_c is only material-dependent is still a problem under investigation. For the purpose of specimen testing, the conditions:

$$b > 25 \frac{J_c}{\sigma_Y}, \quad \frac{B}{b} > 1.$$

(b : ligament width of the specimen, B : thickness) have been proposed to guarantee geometry-indenpendent values relevant to a plane strain situation.

Experimental Work

Specimen Preparation and Testing Procedure

8 mm, 23 mm and 38 mm thick C.T. specimens were machined from as-received 10 mm, 25 mm and 40 mm thick plates of an AISI 304 austenitic stainless steel of German origin (X 6 Cr Ni 18-11. Werkstoff Nr. 1.4948), the crack being in the longitudinal direction of the plates. Furthermore, pieces of the 10 mm and 25 mm thick plates were heat-treated under vacuum ($< 10^{-5}$ mm Hg) at 700°C for 4.000 h, and 8 mm and 23 mm thick C.T. specimens were then machined out after the heat-treatment. Note that in both series the 8 mm thick specimens had the in-plane dimensions of 25 mm thick C.T. specimens, only the thickness being at sub-scale.

The thermal aging conditions were so specified because it had been shown experimentally that the impact rupture energy went through a minimum at an aging temperature of 700°C and was not significantly influenced by the aging time between 4.000 h and 20.000 h. Whether such a treatment simulated the actual aging embrittlement in LMFBR structures working at 550°C during many years may be questioned: it looked reasonably pessimistic for an evaluation of the significance of the phenomenon.

The metallurgical effects of this treatment in our specific material were investigated by micrographic examination (Fig. 2): comparative results of various etching techniques showed $M_{23}C_6$ carbides transformed in sigma phase at the grain boundaries and untransformed carbide precipitates inside the grain [19]

The tensile properties of the material, both in the as-received and aged states, were evaluated by tests at 20°C, 380°C and 540°C on cylindrical specimens cut in the transverse direction of the plates, i.e. the loading direction of the C.T. specimens. All the results are set out in Table 1.

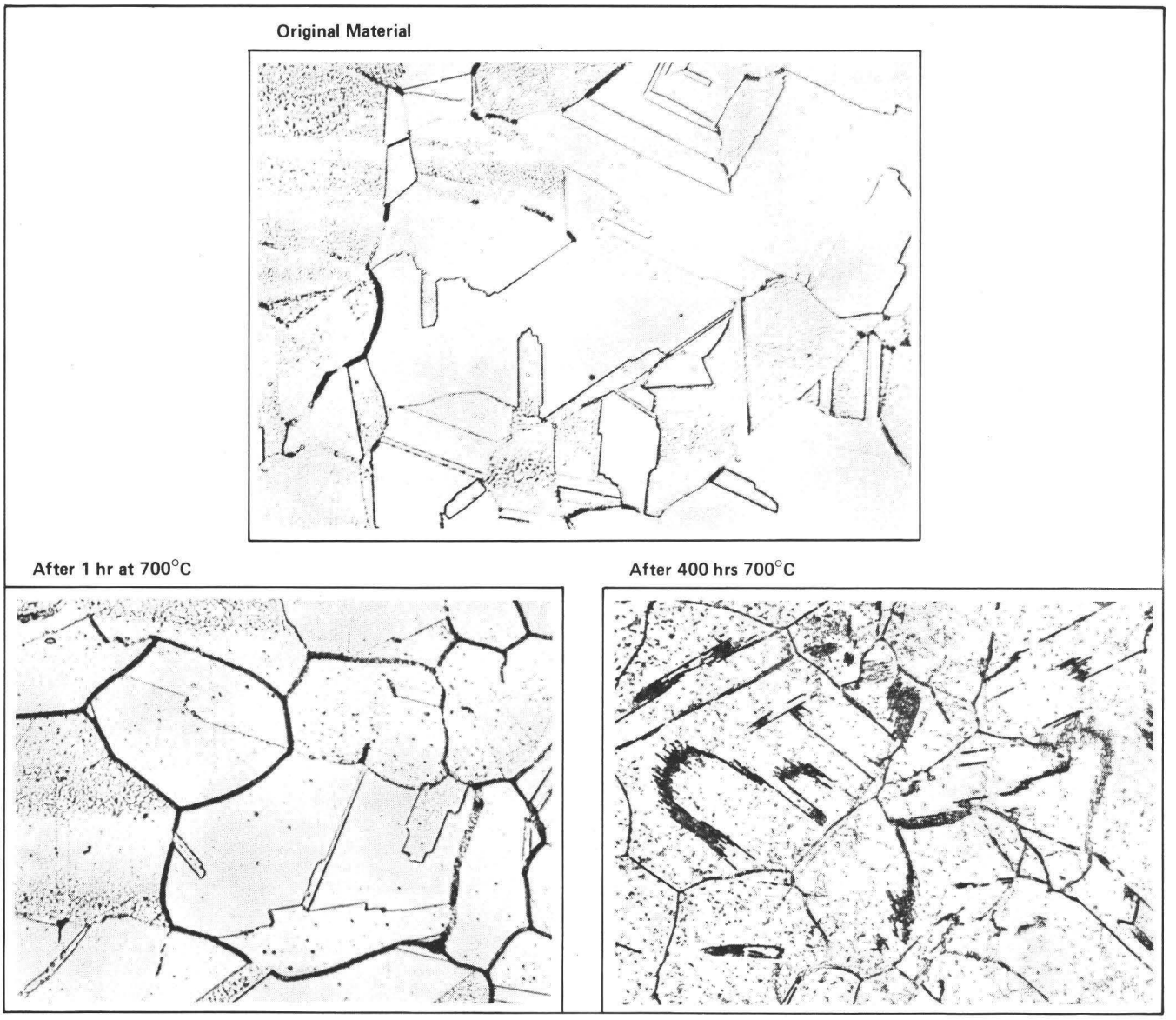


Fig. 2 Effect of Heat Treatment at 700°C on the 10 mm Thick Plate Material

Table 1 : Results of tensile tests on the plate material(1)(2)

test temperature (°C)	plate thickness (mm)	material 'as-received'				700°C - 4000 h aged material			
		$\sigma 0.2\%$ (kg/mm^2) (3)	σ_R (kg/mm^2)	ϵ_R 5.65 $\sqrt{s}$ %	S_R (ϕ6 mm) %	$\sigma 0.2\%$ (kg/mm^2) (3)	σ_R (kg/mm^2)	ϵ_R 5.65 $\sqrt{s}$ %	S_R (ϕ6 mm) %
20	10	25.3	60.5	61.9	70.8	19.1	63.6	53.6	59.1
	25	27.1	59.9	65.2	76.6	22.6	64.4	51.1	59.8
	40	28.0	59.0	65.9	74.4	23.1	64.4	51.1	57.7
380	10	14.9	48.7	46.5	62.9	11.7	43.1	33.3	55.4
	25	15.1	48.4	48.3	69.0	12.7	43.5	33.4	55.5
	40	16.6	48.1	46.2	64.0	13.1	43.9	33.1	55.5
540	10	14.2	45.1	45.4	65.2	10.0	39.6	33.8	54.3
	25	12.9	44.5	46.7	70.0	11.7	40.0	32.7	55.4
	40	13.7	43.7	46.8	66.4	11.0	39.9	32.5	54.9

(1) each value is the average result of at least 3 tensile specimens
(2) specimens cut in the transverse direction of the plates
(3) incorrect operation of the high-sensitivity strain gauge was discovered after the tests: these values of the yield strength are indicative only

The properties of the three plates appear essentially similar if one expects a tendency for the 0.2% off-set yield strength to be lower in the 10 mm thick plate.
The aging effect is a general decrease of the strength (yield and ultimate) and the ductility (elongation and striction), excepting a slight increase of the U.T.S. evidenced by the tests at room temperature.
A fatigue crack was grown at the bottom of the notch of each specimen, approximately up to the half-width (a/w ≅ 0,5), using an Instrom 6 T cycler, in the following conditions:

thickness (mm)	P_{min} (kg)	P_{max} (kg)	frequency (cpm)	number of cycles
8	300	900	1800	~400,000
23	625	1875	1500	~450,000
38	750	4250	1200	~500,000

The specimens were then pulled beyond their instability load on a 20 T Amsler hydraulic traction machine. The load was monitored by a Bofors load transducer (capacity 5 T for the 8 mm and 23 mm thick specimens, capacity 10 T for the 38 mm thick specimens). The notch flank separation at its free end was measured by a Hottinger transducer (Fig. 3) and plotted vs. the load on a x-y plotter. For high-temperature testing (380 and 540°C), the specimens were heated by regulated infrared lamps. During both cold and hot testing, the crack tip region was observed with a Zeiss field microscope that permits of taking Polaroid pictures at (x 5) magnification of the crack flanks, which were marked by microhardness indentations thus permitting local discrete measurements of the crack flank separation.

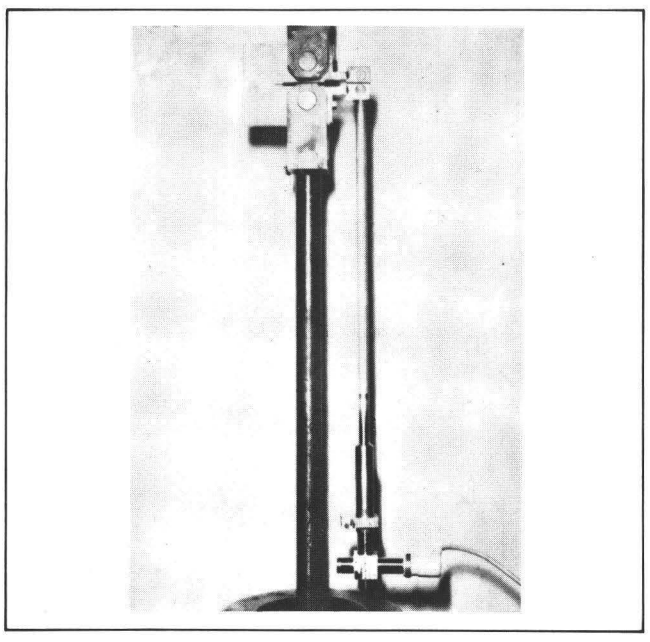


Fig. 3 Experimental Arrangement for the Measurement of the Crack Flank Displacement (△)

The C.O.D. at initiation of the cracking at the end of the pre-fatigue crack, δ_i, was calculated from the notch flank separation at initiation Δ_i using (Fig. 4):

$$\delta_i = \Delta_i \frac{r(w-a)}{r(w-a) + a + z + Z} \qquad (4)$$

The value of r depends on the position of the apparent center of rotation of the notch flanks, for the determination of which the following procedure was used:

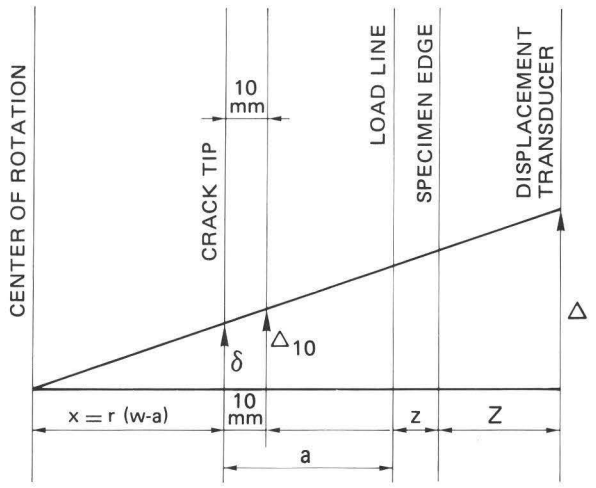


Fig. 4

For one specimen of each set (1 temperature, 1 treatment, 1 thickness), x = r(w-a) was determined on the basis of the transducer data and of the crack flank separation at 10 mm from the crack tip Δ_{10} measured on each available photograph, using the following relationship (Fig. 4);

$$x = r(w-a) = \frac{\Delta_{10} \cdot X - \Delta \cdot 10}{\Delta - \Delta_{10}} \qquad (5)$$

where X = a + z + Z.

A plot of r vs. Δ could thus be determined (Figs. 5, 6,7). Taking into account the field of interest for Δ_i, the following values were chosen for r:

8 mm thick specimens : r = 0.46 (± 0.04)
23 mm thick specimens : r = 0.50 (± 0.06)
38 mm thick specimens : r = 0.51 (± 0.02)

Crack initiation was monitored using the "electrical potential method" [7] which was developed in this laboratory especially for this programme. A 0.1% stability d.c. generator (Lambda Corp.-60A max) supplies a constant current to the specimen through copper wire leads screwed onto the specimen. Potential pick-ups made of 304 stainless steel wire (in order to avoid thermoelectric effects) are welded near the crack tip on each side of the specimen and connected through a x1000 d.c. amplifier to the x-input of an x-y plotter, whilst the signal of the Hottinger transducer measuring the crack flank separation Δ is sent on the y-input. The start of cracking at the bottom of the pre-fatigue crack (blunted under the load) causes a variation of the potential (U) increase rate and a corresponding increase of (dU/dΔ) on the x-y plotter.

In the case of the 8 mm thick specimens very clean potential displacement x-y records (Fig. 8) were obtained, which displayed a pronounced departure from linearity, in the region where optical observations and photographs of the crack revealed crack initiation. In the case of the 23 mm and 38 mm thick specimens, and especially the untreated specimens, the U-Δ records were sometimes more complex and more difficult to interpret (Fig. 9).

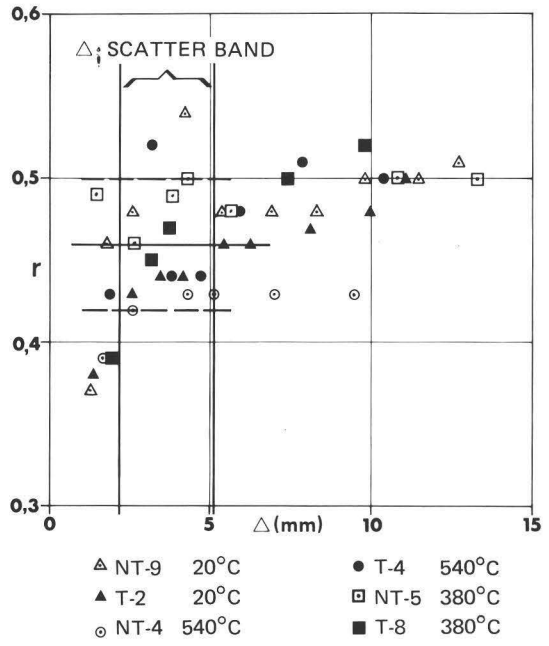


Fig. 5 Value of the Rotation Factor r for the 8 mm Thick Specimens

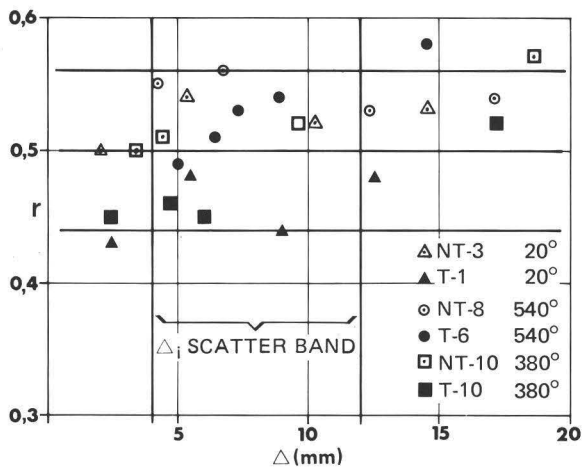


Fig. 6 Value of the Rotation Factor r for the 23 mm Thick Specimens

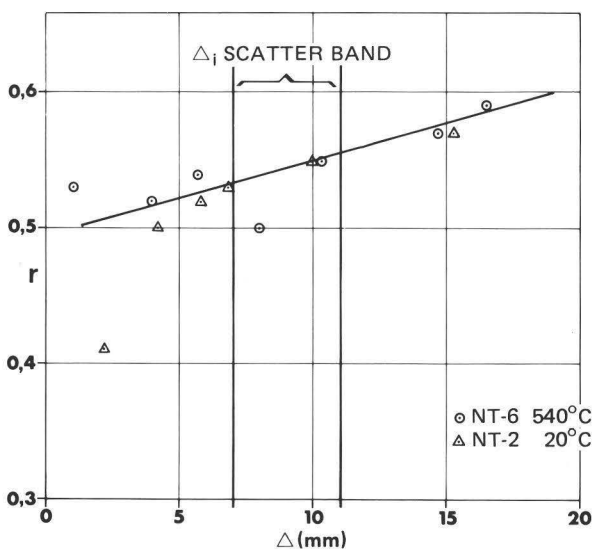


Fig. 7 Value of the Rotation Factor r for the 38 mm Thick Specimens

Generally, these records demonstrated a first du/dΔ-decrease transition, followed by the expected du/dΔ-increase transition. The first transition was not always present and is not clearly understood. The second transition was taken as the signal of initiation, even if some minor cracking sometimes appeared earlier on the surface of the specimen. As a matter of fact, it was shown, looking at the whole crack front inside the specimen during the loading of the 38 mm thick specimens at 20°C, that this cracking stage concerned only a small surface skin of the specimen and on the other hand that the $\frac{dU}{d\Delta}$-increase accompanied the more severe cracking starting inside the specimen and developing then on the whole crack front. The same finding was seen in 23 mm thick specimens, the loading of which was, in preliminary tests, interupted at various levels; after a complete separation obtained by fatigue, the rupture facies could be observed normal to its plane and it was observed that only those specimens that ran past the second $\frac{dU}{d\Delta}$-increase transition had suffered cracking at the bottom of the pre-crack. A certain degree of confidence was therefore put in the method, even if it is considered tricky to use and interpret as regards the largest specimens.

The value of the J-integral at incipient cracking was based on the relation given by Rice, Paris and Merkle [8],

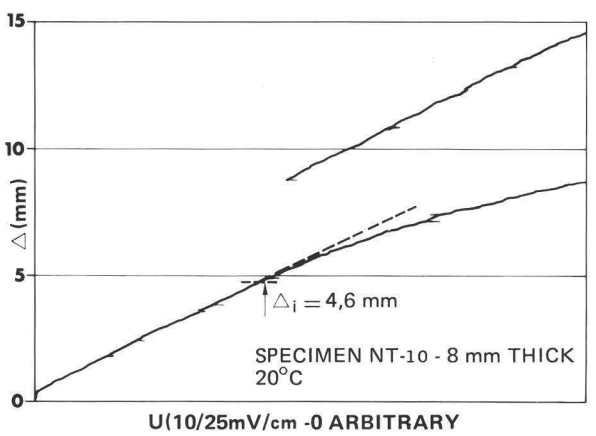


Fig. 8 Example of U-△ Record for 8 mm Thick Specimens

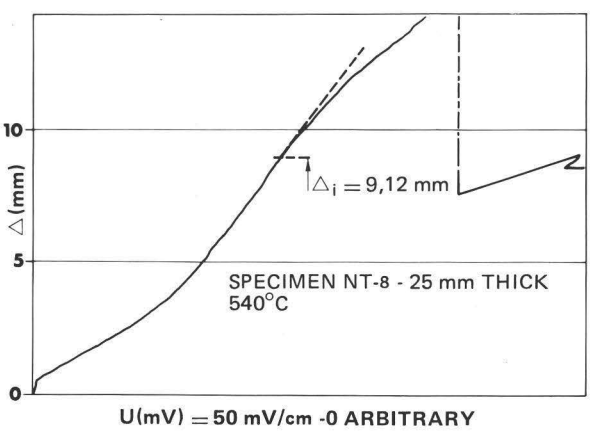


Fig. 9 Example of U-△ Record for 23 mm Thick Specimens

valid for specimens essentially deformed in bending:

$$J_i = \frac{2 A_i}{B (w - a)} \qquad (6)$$

where A_i is the area under the curve load/corrected displacement of the load, at the instant of crack initiation and B, w and a are respectively the thickness, the width and the crack length of the specimen. Parallel tests [9] showed that this formula gave results quite similar to those obtained by the direct measurement of $\frac{\partial u}{\partial a}$ using specimens with different crack length [6] and that the correction to be made to the displacement of the load was inferior to 1% in this practical case and could therefore be neglected. The limitations in the validity of this measure due to the limited specimen dimensions are discussed in section 4.

The load displacement which enters in A_i in (eq. 6) was deduced from the measurement of displacment of the crack flank separation Δ by an experimental calibration on one specimen of each type.

Results and Discussion

The values of δ and J at crack initiation, determined as explained in section 3, are summarized in Table 2 and in Figs. 10 and 11. Some data are missing owing to some instrumentation failures or some unexplained disturbance in the U–Δ plots which precluded a sufficiently reliable determination of the transition in correspondence with initiation.

All specimens failed by ductile tearing followed by plastic instability. Typical P–Δ curves are represented in Figs. 12 and 13, where it can be seen that initiation of ductile tearing noticeably precedes the maximum of the load. The implication of such a feature for the significance of the tests is discussed in section 5.

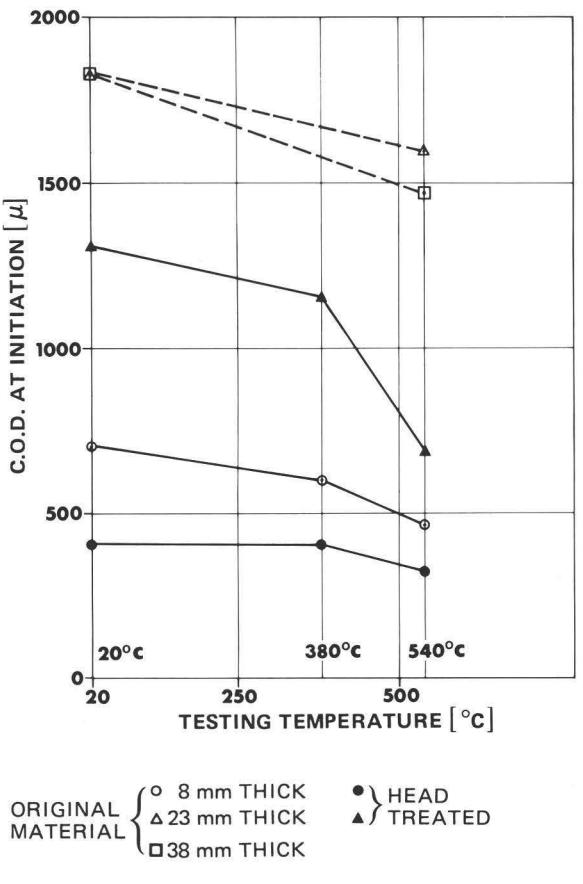


Fig. 10 C.O.D. at Initiation vs. Temperature, Thickness and Heat Treatment

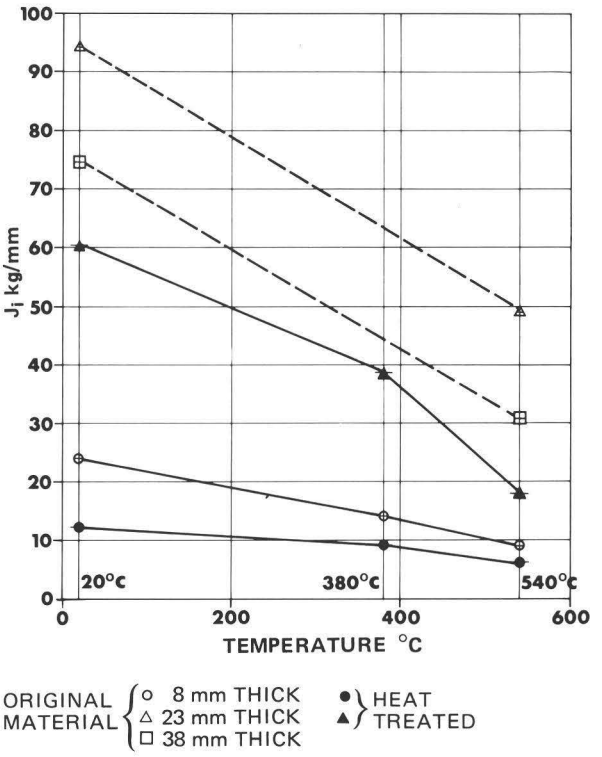


Fig. 11 Variation of J at Initiation vs. Temperature, Thickness and Heat Treatment

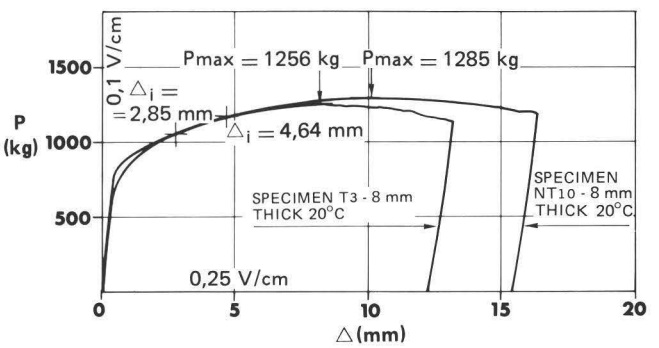


Fig. 12 Example of Load-displacement Diagram for 8 mm Thick Specimens

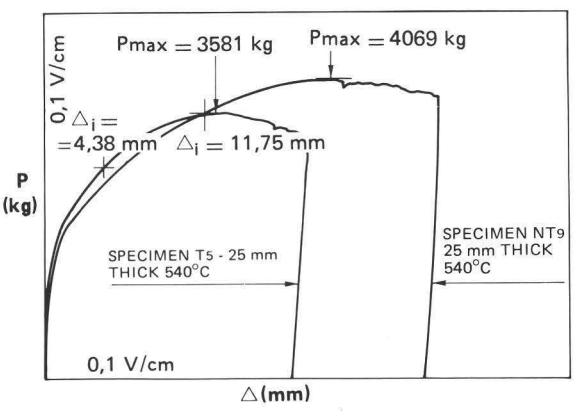


Fig. 13 Example of Load-displacement Diagram for 23 mm Thick Specimens

Table 2 : C.O.D. and J values at cracking initiation

Spec. ref.	J_i kg/mm		δ_i mm		σ_y kg/mm^{-2}	σ_u kg/mm^{-2}	$J_i/\sigma_y\delta_i$		$J_i/\bar{\sigma}\delta_i$		Temp.	
NT8	23.22		0.693				1.32		0.78			
NT9	23.96	23.4	0.72	0.701	25.3	60.5	1.31	1.32	0.77	0.78		
NT10	23.13		0.687				1.33		0.78		20	
T1	12.60		0.392				1.68		0.78			
T2	13.06	12.7	0.408	0.405	19.1	63.6	1.68	1.64	0.77	0.76		
T3	12.31		0.416				1.55		0.72			
NT1	12.24		0.524				1.57		0.73			
NT2	16.85	14.6	0.669	0.601	14.9	48.7	1.69	1.63	0.79	0.76		
NT5	14.45		0.609				1.63		0.77		380	
T7	(1)		(1)				(1)		(1)			
T8	9.30	9.37	0.420	0.408	11.7	43.1	1.89	1.96	0.81	0.84		
T10	9.44		0.397				2.03		0.87			8 mm thick specimens
NT3	10.88		0.540				1.42		0.68			
NT4	8.09	9.49	0.395	0.467	14.2	45.1	1.44	1.43	0.69	0.69		
NT7	(2)		(2)				(2)		(2)		540	
T4	(3)		(3)				(3)		(3)			
T5	6.33	(6.33)	0.325	(0.325)	10.0	39.6	1.95	(1.95)	0.79	(0.79)		
T6	(4)		(4)				(4)		(4)			
NT2	(5)		(5)				(5)		(5)			
NT3	94.25	94.4	1.723	1.831	27.1	59.9	2.91	1.91	1.26	1.19		
NT4	94.59		1.940				1.80		1.12		20	
T1	58.20		1.276				2.02		1.05			
T2	63.97	60.6	1.373	1.308	22.6	64.4	2.06	2.05	1.07	1.07		
T3	59.62		1.274				2.07		1.08			
T7	29.03		0.929				2.46		1.11			
T8	39.20	38.8	1.148	1.154	12.7	43.5	2.69	2.63	1.22	1.19	380	
T10	48.19		1.387				2.74		1.24			23 mm thick specimens
NT7	(6)		(6)				(6)		(6)			
NT8	40.61	50.0	1.405	1.591	12.9	44.5	2.24	2.42	1.01	1.09		
NT9	59.33		1.777				2.59		1.16		540	
T4	15.50		0.608				2.18		0.99			
T5	17.91	18.3	0.662	0.689	11.7	40.0	2.31	2.27	1.05	1.03		
T6	21.54		0.797				2.31		1.05			
NT3	61.40		1.564				1.40		0.90			
NT4	76.28	74.9	1.873	1.835	28.0	59.0	1.45	1.45	0.94	0.94	20	
NT5	87.11		2.067				1.51		0.97			
NT9	(7)		(7)		16.6	48.1	(7)	(7)	(7)	(7)	380	
NT10	(7)		(7)				(7)					
NT6	41.12		1.642				1.83		0.87			
NT7	40.73	39.1	1.622	1.573	13.7	43.7	1.83	1.81 ±2%	0.87	0.86	540	
NT8	35.48		1.454				1.78		0.85			38 mm thick specimens

(1) Unexplained disturbance of the U-Δ curve. Optical value of $\delta_i = 330 - 690\ \mu$
(2) Failure of the potential measurement chain
(3) Unexplained disturbance of the U-Δ curve
(4) idem. Optical value of the C.O.D. at initiation: 290 - 450 μ
(5) Failure of the Δ-measurement chain
(6) Three slight transitions on the U-Δ plots
(7) Unexplained disturbance on the U-Δ curve

In the 8 mm thick specimens, the crack extended generally in its original plane, except for the heat-treated specimens when tested at 380°C and 540°C; in these, crack growth at the specimen surface developed slantwise to the initial crack plane (formation of shear lips). For both untreated and treated specimens, the C.O.D. and J values at initiation decrease slightly when the testing temperature is increased. On the other hand the heat treatment has a perceptible effect on both parameters at room temperature and 380°C. At 540°C, in spite of weaker experimental evidence due to the lack of data for the heat-treated specimens, the emerging trend is similar to that at 20°C and 380°C.

In the 23 mm thick specimens, the crack extended slanted on both sides of its original plane in all the heat-treated specimens. In the untreated specimens at 20°C, the crack remains in its initial plane while for the untreated specimens tested at 380°C and 540°C the two situations are present, depending on the specimen. The trends of the cracking mode are therefore the same as for the 8 mm thick specimens. The C.O.D. and J values are definitively higher than those relating to the 8 mm thick specimens. The trends of the temperature and heat-treatment effects are however the same, the strongest influence of the latter being evidenced by testing at 540°C.

In the 38 mm thick specimens, for which only results relating to untreated specimens are available, the crack extended in its original plane. The C.O.D. values are substantially the same as for the 23 mm thick specimens while the J values are slightly lower.

In these results some features deserve special attention:

a) the variation of J_i vs. temperature, thickness and heat treatment is quite similar to that of δ_i;

b) the C.O.D. (and J) at initiation increase considerably when the specimen thickness increases from 8 to 23 mm.
From 23 to 38 mm, no further increase appears (J even decreases slightly);

c) for all the temperatures and thicknesses, the heat-treatment significantly diminishes the C.O.D. (and J) at initiation, the strongest effect being noted in 23 mm thick specimens at 540°C.

The first of these findings is quite noteworthy when one considers that the values of both parameters, J_i and δ_i, result from independent measurements. As a matter of fact, it is supported by (eq.3), valid for a non-strain-hardening material. For a strain-hardening material, one could hope that (eq. 3) would hold, replacing σ_y by some arbitrary flow stress, for instance: $\bar{\sigma} = (\sigma_y + \sigma_u)/(2)$.
The values of $(J_i)/(\sigma_y \delta_i)$ and $(J_i)/(\bar{\sigma}\ \delta_i)$ are given in Table 2. The values of the second expression are more constant and fall in the range 0.8 – 1.2.

In order to better understand the finding under b), it should be noted from Table 3 that the currently proposed criterion of validity for the measurment of the critical J-integral value – i.e. thickness B and ligament width $b > 25 \frac{J_c}{\sigma_y}$ – are satisfied only by the 8 mm thick specimens as far as b is concerned and not at all by the larger specimens.

If again σ_y is substituted by $\bar{\sigma}$ in the above criteria, both are nearly completely satisfied for the 8 mm and 38 mm thick speicmens, but not for the 23 mm thick specimens (excepted for the aged specimens when tested at 540°C). This apparently paradoxical situation calls for the following comments.

Table 3 : Values of $25\ J_i/\sigma_y$ (or $25\ J_i/\sigma$) to be compared to b and B

			$25\ J_i/\sigma_y$ (mm)	$25\ J_i/\bar{\sigma}$ (mm)
B = 8 mm b ≅ 25 mm	NT	20°	23*	13.6*
	T		16.6*	7.7**
	NT	380°	24.5*	11.5*
	T		20.0*	8.5*
	NT	540°	16.7*	8.0*
	T		15.8*	6.4*
B = 23 mm b ≅ 25 mm	NT	20°	87.1	54.2
	T		67.0	34.8
	NT	380°	–	–
	T		76.4	34.5
	NT	540°	96.9	43.5
	T		39.1	17.7**
B = 38 mm b ≅ 40 mm	NT	20°	66.9	43.0**
	NT	380°	–	–
	NT	540°	71.3	34.1**

(*) valid for b
(**) valid for b and B

Irrespective of the fact that the 8 mm thick specimens fulfil the criterion for a sufficient in-plane constraint ($b > 25\ J/\sigma_y$), it is suggested that the corresponding J_i values characterize the elasto-plastic toughness for this particular thickness. As a matter of fact, it was demonstrated in the tests mentioned above [9] that the variation of the in-plane dimensions of 8 mm thick specimens of the same material was without influence on the J_i values for ligament widths b greater than about 25 mm, a range in which the present C.T. specimens are included. In this range of toughness decreasing with thickness, the fulfilment of the criterion $B > 25 \frac{J}{\sigma_y}$ by the 8 mm thick specimens obviously loses its significance in terms of out-of-plane constraint.

As far as the 23 mm thick specimens are concerned, neither the in-plane nor the out-of-plane constraint criteria are fulfilled and the J_i corresponding values cannot even be considered as characterizing the toughness for this particular thickness. If one accepts the same trend of variation of J_i vs. ligament width as that found for 8 mm thick specimens [9], the apparent J_i values reported here would be ***greater*** than those characterizing the 23 mm thickness.

Finally, for the 38 mm thick specimens, the criteria for in-plane and out-of-plane constraint are fulfilled and the corresponding J_i values are accepted not only as characterizing the 38 mm thickness but also as relevant to a plane strain regime. This understanding of the evidenced variations of J_i (and δ_i) vs. thickness is summarized in Fig. 14. Valid measurements (i.e. in-plane constraint sufficient to allow a thickness-characterizing measurement) are available at 8 mm and 38 mm. In between, two different trends of variation can be postulated: a continuous increase or an increase – maximum – decrease in analogy with the postulated variation of K_c vs. thickness.

The result under c) above means that the presence of brittle components both inside the grains and at the grain boundaries, while not producing a change of the rupture process from ductile to brittle even in the presence of a sharp crack, causes a decrease of the material's resistance to ductile tearing. One can observe that this diminution is much more perceptible than that of the rupture elongation or the reduction of area measured in the tensile tests (Table 1). The structural significance of this effect is discussed in the following section.

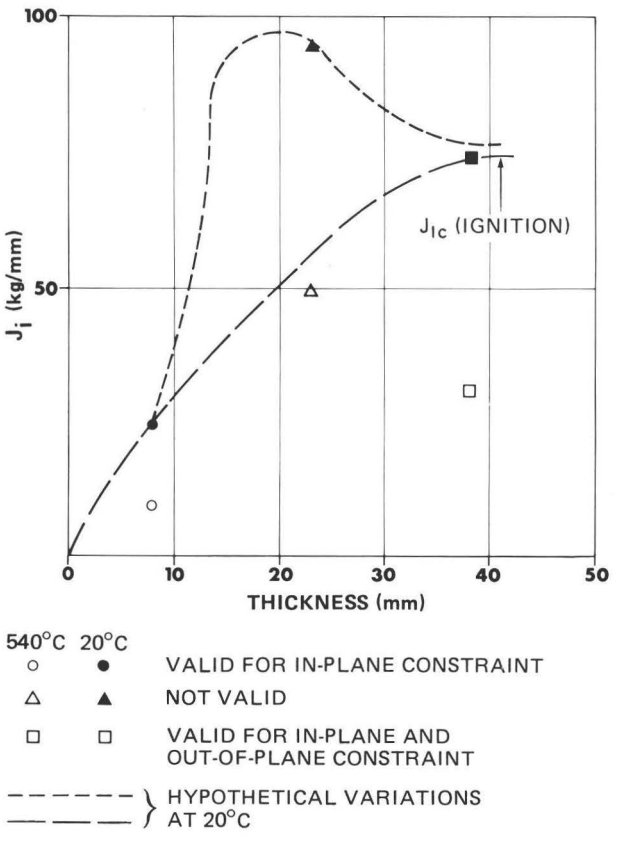


Fig. 14 Summary of the J_i-Variation vs. Thickness

Practical Significance of the Results

The question to be answered at this point is: in engineering terms, what is the practical meaning of the damage resulting from thermal aging characterized by the tests reported above ?

A first point to comment on is the fact that this characterization was based on the C.O.D. (and J) values at crack *initiation,* and not at maximum load, due to the geometry dependence and/or the loss of significance of these parameters after crack initiation [11, 6]. As a result any prediction based on these δ_i or J_i values will be relative to the initiation conditions in the structure and not to the failure or instability conditions. This remarks seems pertinent as it may be seen in Figs. 12 and 13 that the initiation significantly precedes the instability and one could therefore argue that a prediction based on δ_i (or J_i) is too pessimistic.

It has, however, found by experiment on a series of 8 mm thick specimens of the same material, statically loaded at 550°C at a level corresponding to initiation under monotonic loading, that the creep lifetime is below 100 hours [12]. One can therefore suspect that if in a real austenitic steel structure at 550°C – e.g. a LMFBR primary pipe – a crack reached a dimension corresponding to that of initiation under monotonic loading up to a level corresponding to the operating stress, failure would follow very rapidly as a result of creep crack growth. Thid finding justifies our accepting initiation as the critical point to characterize failure in our specimens for this specific application. On the other hand, it should be recognized that the implications of creep crack growth could go well beyond this particular conclusion and deserve more attention in the future. A practical example of the application of the preceding results will be given now, once more considering the case of a primary pipe of a LMFBR reactor loop operating at 550°C, having the following approximate dimensions: external diameter 600 mm; thickness 8 mm.

It is desirable to know how much the critical crack length under the operating primary membrane stress, assumed to be 4 kg/mm^2, is diminished as a result of thermal aging embrittlement. To determine this it would be necessary to know the "design relationship" between C.O.D. (or J), load, and defect dimensions relative to this geometry. However, no elasto-plastic analysis or results of experimental calibration are available for this practical situation. One has therefore to rely on a formulation of the stress intensity factor K applicable to a cylindrical shell – such as that of Hahn et al. [15] – and to accept some relationship between K and δ (or J). In a previous work [13, 14], crack instability in through-cracked tubes in AISI 304 stainless steel was investigated by hydraulic burst tests and a critical stress intensity factor value, K_c, of about – 370 kg/mm$^{-3/2}$ – fairly independent of the tubing geometry and the crack dimensions – was found to describe the failure conditions (at 20°C), using the above mentioned Hahn correlation.

On the other hand one may retain from (eq. 1) and (eq. 3) that for other material properties a proportionality relationship should be maintained between K_c^2 and the product $E\bar{\sigma}\delta_c$ (or again the product EJ_c). Therefore

$$(K_c)^{540°C}_{tube} = K_c{}^{20°C}_{tube} \times \sqrt{\frac{(E\bar{\sigma}\delta)^{540°C}_{specimen}}{(E\bar{\sigma}\delta)^{20°C}_{specimen}}}$$

or

$$(K_c)^{540°C}_{tube} = K_c{}^{20°C}_{tube} \times \sqrt{\frac{(EJ)^{540°C}_{specimen}}{(EJ)^{20°C}_{specimen}}}$$

Note that these two calculations are practically equivalent as $J_i = \bar{\sigma}\delta_i$ within 20% scattering in our specimens.

The corresponding K_c values for the tube at 540°C are:

- untreated material (E = 13375 kg/mm^2, $\bar{\sigma}$ = 29,6 kg/mm^2, $\delta_i = 470\,\mu$): 204 kg • mm$^{-3/2}$
- temperature-aged material (E = 13375 kg/mm^2, $\bar{\sigma}$ = 24,8 kg/mm^2, $\delta_i = 325\,\mu$): 155 kg • mm$^{-3/2}$

Using the Hahn and al. correlation again, these values may be used to predict the critical crack length/hoop stress relationship for the different states of the material. The corresponding curves appear in Fig. 15. It can be seen on these curves that the critical crack length corresponding to an operating stress of 4 kg/mm^2 at 540°C would be reduced from 230 mm to 180 mm as a result of the thermal aging affect.

The approximative and empirical character of this prediciton should be emphasized. However, its conservative character has been demonstrated by burst testing of part-through cracked tubes at 540°C [18]. It seems sufficient to show that the temperature aging of the austenitic steel – as represented by the simulation treatment involved in our tests – would not significantly increase the danger of unforeseen large-scale rupture.

Acknowledgements

This work was done under a contract of cooperation with Interatom – G.m.b.H. – Bensberg (contract 074-72-PIPGD). The author is indebted to his colleague J. Bernard for a number of fruitful discussions, to Mr J.M. Sprauel for his help in the processing of the results and to Mr Manzotti, Mr Roumengous and Mr Tognoli for their technical assistance.

The contribution of Dr. Matera and Mr Cazzaniga who investigated the micrographic effects of the heat treatment is gratefully acknowledged.

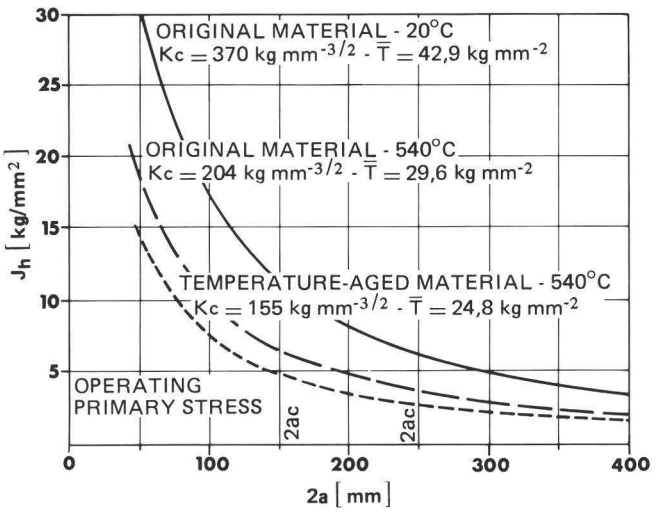


Fig. 15 Prediction of the Effect of Temperature Agin on the Hoop Stress - Critical Crack Lenght Relationship in a 600 mm Dia. - 8 mm Thick Tube in Aisi 304 Stainless Steel

References

1) A.A. WELLS, *British Welding Journal,* November 1963.

2) "Methods for C.O.D. Testing". BSI Document DD 19 (Draft for Development).

3) E.F. BOYLE, Ph. D. thesis – Quee's University of Belfast, 1972.

4) BURDEKIN & DAWES, "Conference on Practical Application of Fracture Mechanics to Pressure Vessels" London, 1971, Paper C5/71.

5) J.R. RICE, *J. Appl. Mech.* June 1968.

6) BEGLEY & LANDES, The J-Integral as a Fracture Criterion, STP514, ASTM.

7) J.M. LOWES and G.D. FEARNEHOUGH, *Eng. Fract. Mech.,* **Vol. 3,** 1971.

8) J.R. RICE, P.C. PARIS, J.G. MERKLE, Some further Results of J-Integral Analysis and Estimates. ASTM – STP.536.

9) R.F. MONTGOMERY, J-Integral Measurements of Various Types of Specimens in AISI 304. JRC Ispra, Technology, EUR Report to be published.

10) J.E. STRAWLEY and W.F. BROWN, ASTM–STP 381.

11) G.D. FEARNEHOUGH et al., Conference referred to in [4]. Paper C33/71.

12) B. HENRY, Creep Crack-Growth Screening Tests. 1974, Ispra Safety Programme Report (not available).

13) G.T. HAHN et al., Criteria for Crack Extension in Cylindrical Pressure Vessels. *Int. J. of Fract. Mech.,* **Vol. 5, no. 3,** September 1969.

14) B. HENRY, J. BERNARD, Fracture Criteria for AISI-304 Tubing, Annual Report Ispra 1972, EUR 5060.

15) J. BERNARD, B. HENRY, Etude expérimentale de l'effet de la carbure sur la valeur du facteur d'intensité de contrainte dans les coques cylindriques, EUR 5137 f.

16) D.J. HAYES, Ph. D. Thesis, University of London, 1970.

17) Mc. CLINTOCK, HUTCHINSON, RICE and ROSENGREN, referred to by [6].

18) B. HENRY, Application of Fracture Mechanics to the Prediction of Rupture Behaviour of Thin Cylindrical Structures. 3rd SMIRT, London, 1975, Paper L7/5.

19) R. MATERA and E. CAZZANIGA, Material Department, JRC. Private Communication.

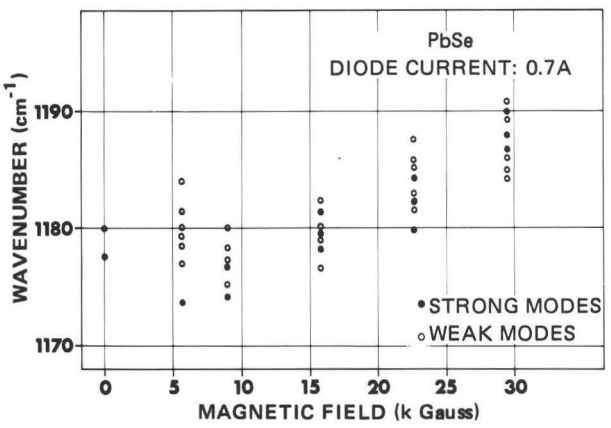


Fig. 4 Dependence of a PbSe Laser Emission Modes on Magnetic Field at a Fixed Diode Current

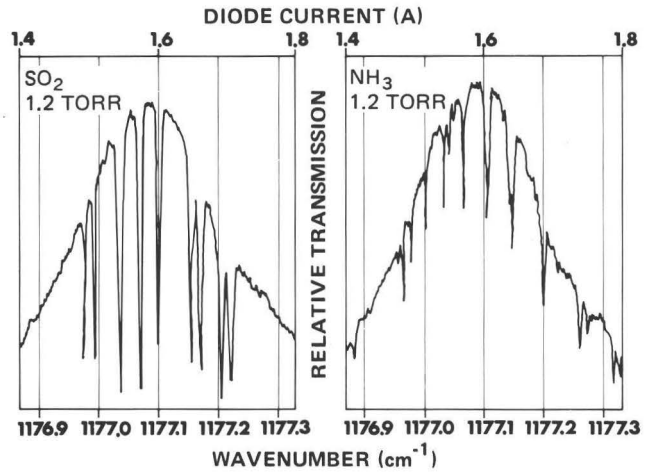


Fig. 5 Diode Laser Scans of SO_2 and NH_3 Gas at the Pressure of 1.2 Torr in a 30 cm Cell

Point Sampling

The IR absorption spectrum of a polluted atmosphere is at best complicated. Especially at moderate or low resolution (atmospheric pressure broadened lines) serious overlapping of the apparent spectral lines preclude even the qualitative identification of a particular molecular species in an unknown mixture.

In order to extract the maximum infomation from the absorption technique, high-resolution spectroscopy has to be performed. This can be done in a closed cell by suitably reducing the total pressure down to few torr, and in open atmosphere at high altitudes; for in such conditions the molecular absorption lines are Doppler-limited (30 – 100 MHz) as against ground-level (atmospheric pressure broadened) line widths of 2 – 3 GHz. The narrow linewidth of the absorption spectrum at low pressure, strongly reduces the possibility of overlapping and hence of interference from the other gases present in the mixture.

There are a number of important uses for point sampling and laboratory spectroscopy (ambient air pollution monitoring, automobile exhaust analysis, etc.) that profit from the extremely high spectral resolution and specificity of tunable diode laser spectroscopy.

In-cell measurements were undertaken in this laboratory, chiefly to determine the diode laser characteristics and the suitability of an absorption line to in-field monitoring. Fig. 5 shows typical scans of wavelength regions of SO_2 and NH_3 absotption spectra.

Fig. 6 gives a view of the apparatus used for in-cell measurements, together with a diagram of the system.

Remote Detection and Long Path Monitoring

The purpose of this programme is to develop tunable diode laser techniques for "in field" continuous ambient air monitoring. Unlike "in-cell" experiments, open-air operation is affected by considerable handicaps primarily represented by the pressure broadening of the molecular absorption lines and by the atmospheric transmittance and noise.

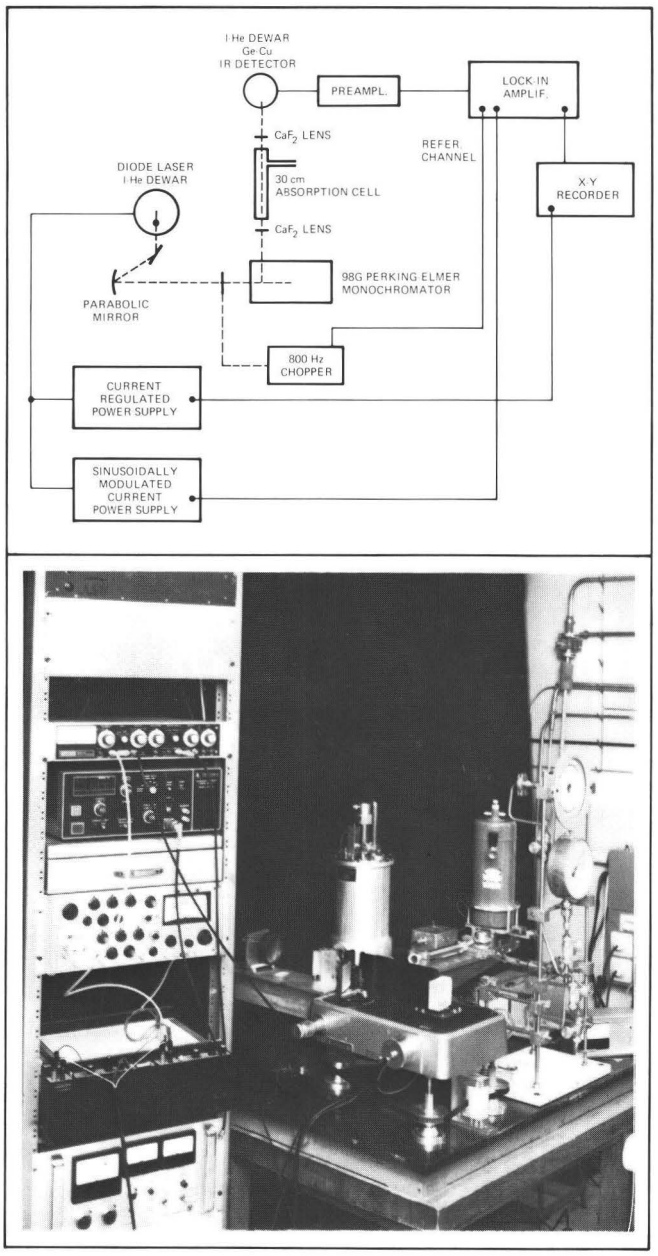


Fig. 6 View of the Apparatus Used for "In Cell" Spectroscopy, with a Diagram of the System

Wavelength Considerations for Long Path Monitoring

The adverse effect of increasing the total gas pressure on the absorption spectrum is illustrated in Fig. 7 The direct transmission spectrum and the derivative spectrum of a low pressure (1 torr) NH_3 gas in a 30 cm cell are shown in the upper part of the figure. Note that one torr in a 30 cm cell corresponds to a mean concentration of 400 ppb over one km path length.

The total gas pressure in the cell was then increased by adding nitrogen to the values indicated; the corresponding derivative spectra are shown. The derivative detection method is used to increase the sensitivity of the measurement.

At atmospheric pressure (760 torr) the absorption lines of the original spectrum appear completely useless for in-field monitoring. This demonstrates that absorption spectra in atmospheric pressure broadened regime have to be analysed in order to select the most suitable wavelength. An ideal absorption line or band should in fact maintain in atmospheric pressure broadened regime a sufficiently high effective absorption coefficient and should be reasonably free from interference from other pollutants or atmospheric constituents. This is the case of the P(4) and P(3) lines of CO as demonstrated by Ku et al. [2].

It is planned to use one of these two lines for preliminary "in-field" experiments.

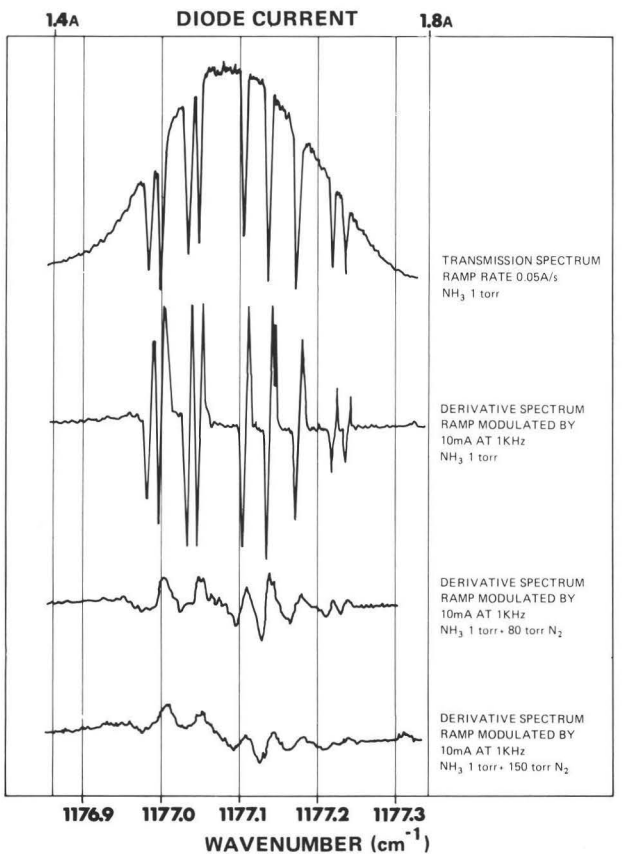


Fig. 7 Direct Transmission Spectrum of NH_3 and Derivative Spectra at Different Total Gas Pressures Obtained by Adding Nitrogen in the Cell

Atmospheric noise

In long-path measurement, the laser beam must travel a path of some hundreds of metres in the atmosphere. It is then necessary to account for the effects due either to the standard constituents of a clean atmosphere or to meteorological conditions. The first effect depends upon the fact that water vapour and carbon dioxide absorption black out some regions of the spectrum (2.5 – 2.9 μm; 4.2 – 4.4 μm; 5.5 – 7.5 μm; above 14 μm). The effect of H_2O and CO_2 even in the atmospheric windows has to be carefully considered, since sizable attenuation of the beam can result. The second effect arises from the presence of thermal fluctuations in the atmosphere (turbulence) which result in fluctuations of the received signal strength. The problem of beam defocusing and steering can be minimized by suitable design of the optics (see below). The effect of atmospheric turbulence can be minimized by performing the measurement of the signals ON and OFF resonance in a sufficiently short time, so that the atmospheric transmittance will be practically unchanged during the scanning of the absorption line.

Ku et al. [2] have demonstrated that short-term turbulence and scattering effects are reduced considerably by scanning the absorption line in a time not longer than 0.1 msecond. The procedure followed by those authors will be used in this work. The diode current, set for a laser emission wavelength corresponding to the absorption line, was modulated with a small superimposed sinusoidal current at high frequency (~ 10 kHz). Since this method modulates the laser emission wavelength was well, the derivative of the absorption spectrum was obtained by synchronous detection at 10 kHz. As above indicated, at this frequency the atmosphere is effectively frozen. To take into account fluctuations in the laser emission intensity, the direct transmission signal is obtained by intensity-modulating the laser beam at a lower frequency (chopper at ~ 170 Hz) and synchronous detection. The derivative and the direct transmission signal are then ratioed. Mathematically it can be shown that the final signal is independent of the turbulence and scattering parameter, so that displayed on a strip-chart recorder it provides a continuous record of the averaged pollutant concentration along the path of the laser beam.

The received laser power I can be expressed as

$$I = I_o \exp(-\alpha_\nu \cdot c \cdot L) \exp[-\beta(t) \cdot L]$$

where α_ν is the line absorption coefficient of the specific pollutant whose average concentration along the beam path L is c, and β (t) is an extinction parameter caused by atmospheric effects other than the pollutant absorption. β (t) is dependent on time and, for the small wavelength region around the selected absorption line, independent of laser emission frequency ν.

The derivative signal $dI/d_\nu = I'$ is equal to

$$I' = -I_o c L \exp(-\alpha_\nu c L) \exp[-\beta(t) L] \cdot \frac{d}{d\nu} \alpha_\nu$$

By rationing I' and I (I' is calculated at a given frequency ν' where the derivative signal is maximum) it can be shown that

$$R = I'/I = \alpha_o \cdot L \cdot c \cdot \text{constants}$$

α_o being the absorption coefficient at line centre.

The schematic layout of the experimental apparatus is shown in Fig. 8.

Measuring Apparatus

We have designed and constructed a suitable optical system for IR laser beam handling over a beam path of some hundreds of metres. For this experiment we intend to collimate the beam towards a corner-cube retroreflector situated at a given distance from the source and to collect the reflected light by means of suitable optics. Experiments performed with a He-Ne laser at the JRC [3] have shown that beam steering and defocusing effects are eliminated if the dimensions of the retroreflector and the collecting optics are suitably chosen.

The JRC Ispra optical system for long-path monitoring is schematically illustrated in Fig. 9, which also shows pictures of the telescope system and of the retroreflector. We use a Cassegrain telescope as collimator (7 cm diameter) and a 25 cm diameter 86 cm focal length Newtonian telescope as collector. Each is in a Coudé mount permitting wide mobility of the telescope without moving the laser source. The corner cube retroreflector is triangular with a side of 30 cm.

We are having some difficulty in coupling the laser source to the telescope, owing to the presence of the monochromator imposed by the multimode emission of the laser source.

Work is also in progress to mount the laser source on the closed-cycle cryogenic cooler (Fig. 10). This device should allow of temperature-tuning the diode laser (in the range 12° – 50°K or more according to the laser characteristics) with only household current. In operation at constant temperature a stability better than 0.01°K (equivalent to about 0.01 cm^{-1} laser frequency fluctuation) can be achieved.

Additional advantages are:

- the system can run continuously without logistic support or operator attendance;
- the cool-down time and room temperature recycling time are considerably reduced;
- the cold head containing the diode is relatively small and rugged.

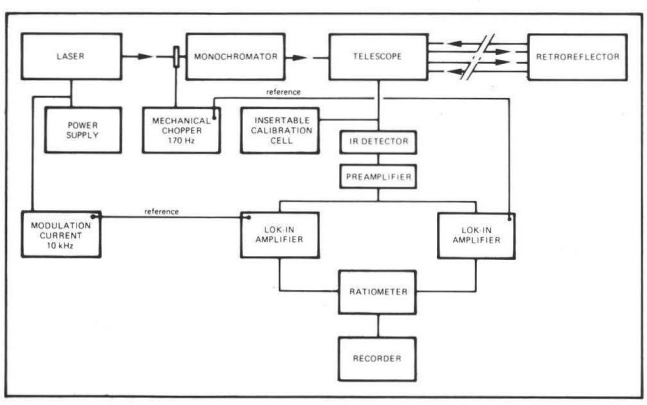


Fig. 8 Schematic Layout of the Experimental

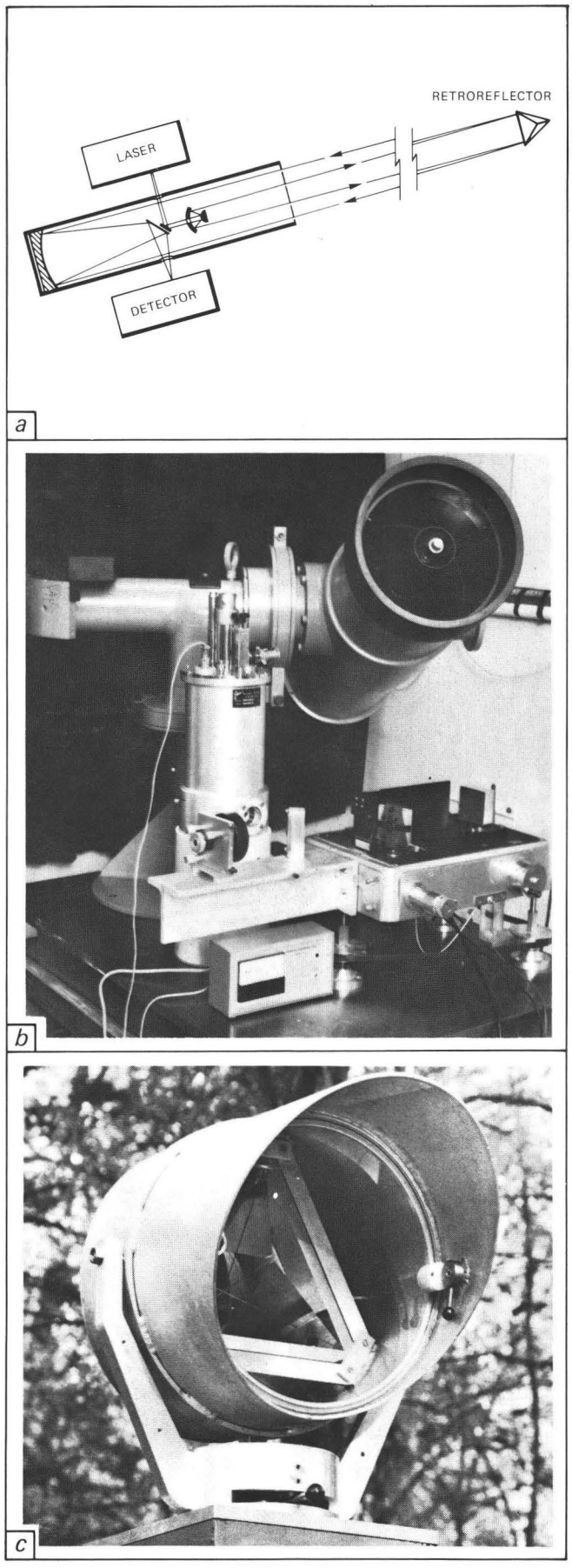


Fig. 9 JRC Optical System for Long Path Monitoring

a. Schematic System
b. Telescope and Laser Source
c. Retroreflector

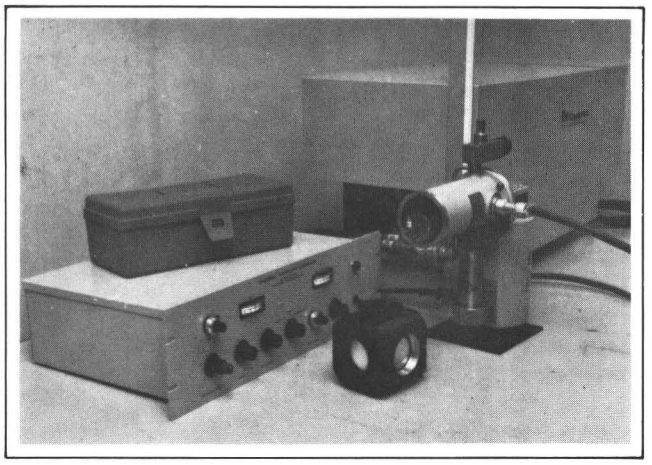


Fig. 10 Cryogenic Technology Mod. 21 Closed-Cycle Cooler System: Temperature Controller, Cold Head and Compressor

Future Outlook

Of all remote sensing systems for global and regional monitoring of ambient concentrations of atmospheric pollutants, the technique of resonance absorption in the infrared range appears capable of giving the highest specificity and sensitivity.

Up to now only one laboratory in the world (MIT Lincoln Lab.) has applied this technique (tunable diode laser) to the monitoring of CO and NO over a 300 m region (double beam path for 600 m total length), calculating a minimum detectable concentration of about 3 ppb of CO over a beam path of 1 km. The same group has demonstrated the operation of a mobile monitoring system utilized at the last St. Louis regional air pollution study campaigns. Proposals for operation of a system based on resonance IR absorption technique with tunable diode lasers from satellite or aircraft platforms have been discussed by NASA (Allario et al., 1973)[4]. In regard to our own research, it is hoped that mWatt lasers, which became commercially available in the second half of 1975, will help to overcome some difficulties encountered with the present diodes (100 – 200 μwatt).

The applicability of the technique to CO and NO has already been demonstrated; its extension to other important pollutant gases like SO_2, O_3, NH_3, CH_4, C_2H_4 etc. still demands close investigation of the molecular absorption spectrum in relation to the atmospheric transmittance for wavelength selection. We also expect to gain some help with this problem from the results of the studies done under the EEC Environmental Research Programme (DG–XII), during the years 1974-1975.

A detailed analysis of the technique of remote detection of atmospheric pollutants by IR resonance absorption using tunable diode lasers has been published as EUR Report 4598 e.[5].

References

1) E.D. HINKLEY, K.W. NILL and F.A. BLUM, Infrared Spectroscopy with Tunable Lasers, in *Laser Spectroscopy of Atoms and Molecules,* 1976 Springer- Verlag, Heidelberg.

2) R.T. KU, E.D. HINKLEY and J.O. SAMPLE, *Applied Optics,* **14,** 854 (1975).

3) S. SANDRONI and C. CERUTTI, EUR 5427 e (1975).

4) F. ALLARIO et al., 10th Anniversary Meeting Soc. of Engineering Science, (November 1973) Raleigh.

5) F. CAPPELLANI, G. MELANDRONE, G. RESTELLI and S. SANDRONI, EUR 4598 e (1975).

High-Power Water Loop in Essor

J. A. Bekkering

Introduction

Two high water loops, to be installed in the ESSOR Reactor, are now under construction. One loop, called Cleopatra, is for pressurized water operation, the other, Cabiria, is for boiling water operation. Each loop is connected to one experimental channel position in the ESSOR Reactor.

The objectives of the irradiation tests that can be performed in those test channels can be divided into three main groups:

a) study of fuel bundles under stationary conditions;
b) study of fuel bundles under dynamic conditions simulating power-plant operation transients;
c) study of fuel bundles under dynamic conditions simulating, power-plant accidents.

Each loop will be installed in its own bunker.

The Test Channel

Proceeding from inside to outside, at the mid-core plane, the channel is composed of the following components:

- the pressure tube in Zr–2.5% Nb
- the Co_2-filled gap, acting as a thermal insulation between the pressure tube and the safety tube
- the safety tube in Zr-2.5% Nb, designed to withstand the full primary pressure
- the D_2O-filled gap in forced circulation to cool the safety tube
- the posion sleeve, acting at the same time as a guide tube for the heavy water
- the moderator heavy water.

The dimensions of the test channels are essentially limited by the bore of 170 mm diameter in the upper reactor shield.

The pressure tubes envisaged at present do not cater for the maximum conceivable space inside the test channel, owing to technological difficulties, but in the future a slightly bigger test channel might be possible.

The reference fuel element, constituted of the maximum number of rods that can be fitted into the test channels at present, is based on present PWR and BWR rod diameters and pitches.

To avoid the possibility of hot spots on the pressure tube, and for safer manipulation, the test elements will always be equipped with an external shroud.

This shroud might be of poisoned material to provide for a flux attenuation when ever requested.

Another means of obtaining a flux attenuation is with the poison sleeve situated outside the safety tube.

The main parameters of the test channels and the reference elements are listed in Table 1.

	Cleopatra	Cabiria
Pressure tube ID mm	104.0	120.4
Pressure tube OD mm	126.8	134.1
Safety tube ID mm	135.3	142.5
Safety tube OD mm	152.3	152.1
Poison sleeve OD mm	160°	160°
No. of rods in ref. element	37	32
Rod OD mm	9.5	12.52
Pitch mm	12.6	16.26
Active height of core mm	1500	1500

Figs. 1 and 2 show, respectively, the Cleopatra and Cabiria test channels with reference element.

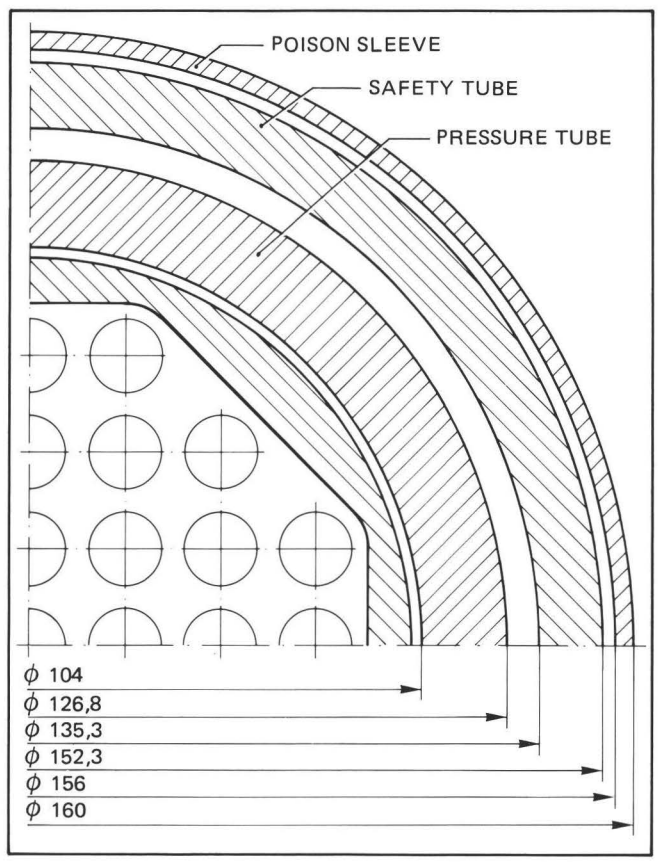


Fig. 1 Cleopatra - Test Channel with Reference Element

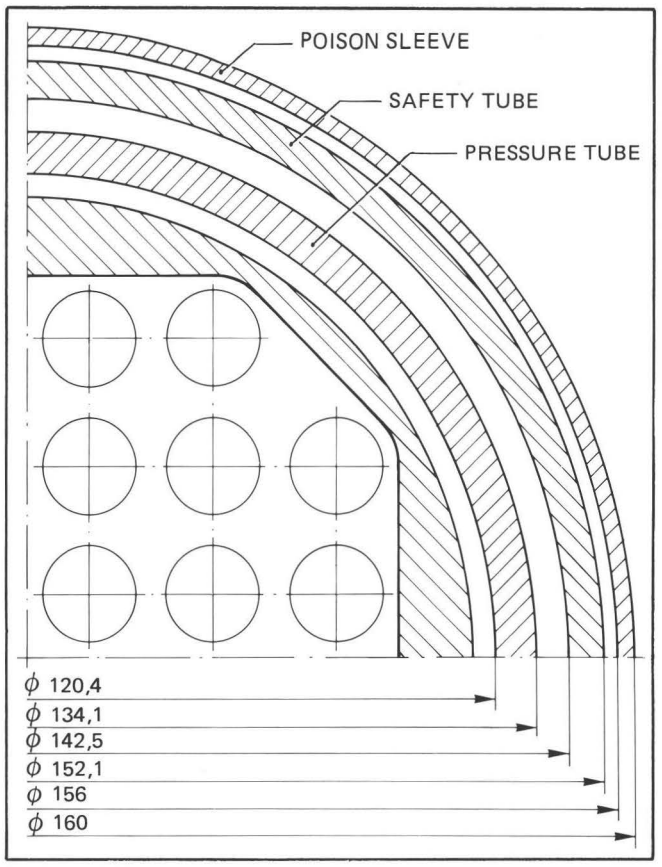


Fig. 2 Cabiria - Test Channel with Reference Element

Short description of the circuits

The main parameters of the circuits are listed below:

	Cleopatra	Cabiria
Maximum power generated in test channel MW	3.15	3.15
Primary pressure, nominal bar	182	91.2
Outlet temperature °C	335	302
Maximum flow kg/sec	28.6	18
Maximum pumping head m	216	220
Pressure drop over test channel bar	5.6	6.1
Design pressure bar	213	115
Design temperature °C	370	320
Power of electric preheater kW	315	
Power of electric steam generator kW		1500
Purification flow kg/sec	3.3	10.-
Maximum quality at channel inlet with total flow of 6 kg/sec		11%

The Cleopatra Circuit

The flow sheet of the circuit is represented in Fig. 3. The primary circuit is composed of the following components:

- the test channel
- the full-flow filter to retain debris
- the main heat exchanger, 3.5 MW
- two canned main circulators in series
- the preheater
- the auxiliary heat exchanger, to cool the element during handling or in case of failure of the main heat exchanger.
- the purification circuit, composed of three mixed-bed ion exchangers, a degassing tank operating at low pressure, and two piston recharge pumps.

The main heat exchanger is cooled by a fully-closed intermediate circuit which in its turn is cooled by the atmospheric cooling tower circuit. The main circulators are cooled by a fully-closed components cooling circuit, in its turn cooled by industrial water.

In this way all components essential from the safety point of view have a double barrier between the primary liquid and the outside atmosphere.

The Cabiria Circuit

The flow sheet of the circuit is represented in Fig. 4. The primary circuit is composed of the following components:

- the test channel
- the full-flow filter to retain debris
- the steam separator
- the expansion tank to compensate for thermal expansion and steam collapse
- two condensors in parallel, 1.8 MW each
- the condensate collecting tank
- two canned condensate return pump (necessary while it was impossible to instale the condensors over the expansion tank)
- two subcoolers in parallel, 580 kW each
- two canned main circulators in series
- the steam generator, composed of 7 electric boilers in parallel with a total power of 1.5 MW.
- the mixer, where subcooled water and steam are mixed to obtain the required test-channel inlet conditions
- the auxiliary heat exchanger to cool the test element during handling or in case of failure of the intermediate circuit
- the purification circuit, composed of the mixed-bed ion exchangers, a degassing tank operating at low pressure and two position recharge pumps.

The main heat exchangers are cooled by two fully-closed intermediate circuits (one for the condensors, and one for the subcoolers) which in their turn transmit the heat to the atmospheric cooling tower circuit.

The main circulators are cooled by a fully-closed components cooling circuit, in its turn cooled by industrial water.

General Characteristics of Both Loops

Each main circulator is fed from its own motor-generator set, equipped with a fly wheel, The motor-generator sets are velocity - controlled, and consequently the velocity of the main circulators can be varied.

The fly wheels are dimensioned to bridge the switching intervals of the electric supply system without significant flow variation in the test channel, and to provide for a safe coast-down in case of a power failure.

The concept of variable speed pumps together with control valves has been adopted to provide for a wide range of control of the flow in the test channel.

In case of a prolonged power failure, the circuits are designed to transfer the decay heat by natural circulation.

Pressurized accumulators and pumps are connected to the inlet and outlet of the test channel to provide for emergency cooling in case of an unscheduled loss of coolant.

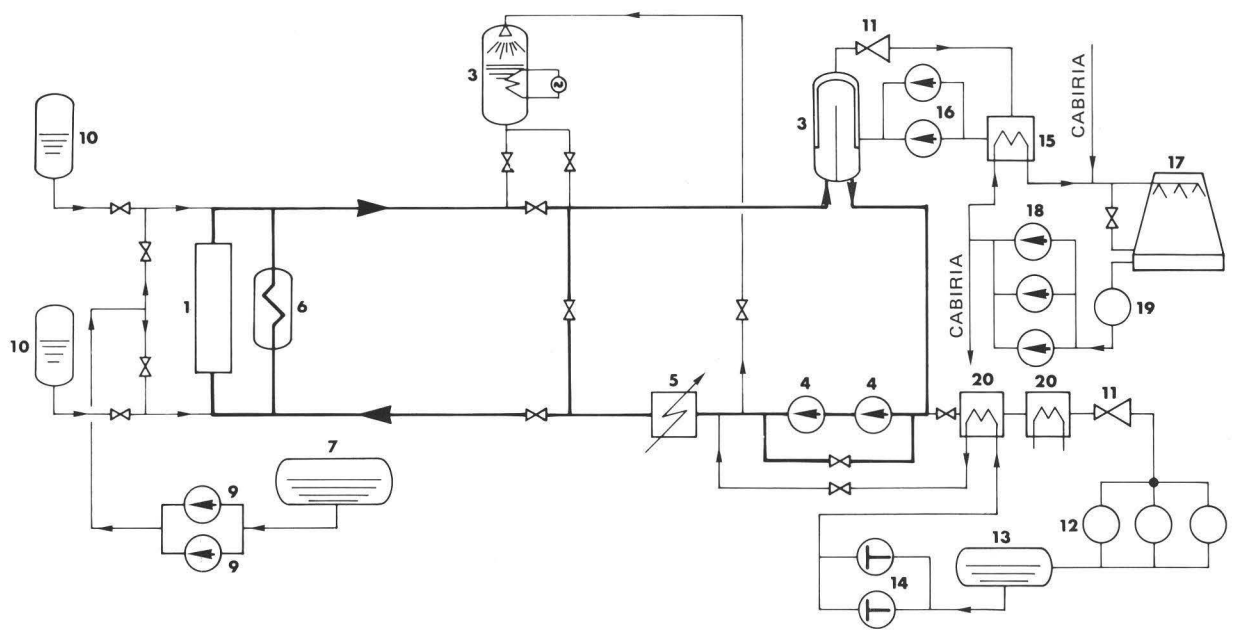
Each loop is installed in its own bunker. These bunkers are not accessible during power operation. A small shielded room was been constructed in a corner of each bunker, with direct access from outside, and here samples can be taken.

At present the loops will not be equipped for the execution of safety tests (loss of coolant accident, loss of flow accident etc.).

In future, however, valves can be installed to allow the test channel to be isolated from the circuit and to provide blow-down lines from both ends of the test channel to the quench tank.

Further more, space will be reserved to allow for the installation of additional components necessary to simulate the conditions occurring during a reactor accident (f.e. and additional tank simulation the lower plenum, pressurized accumulator and pumps simulating the emergency cooling system in a reactor).

The contract for construction of the circuit was signed recently (February 1976) and the loops are expected to be operative for nuclear use around the beginning of 1979.



1. Test section
2. Pressuriser
3. Condenser - vapour generator
4. Primary circulation pumps
5. Preheater
6. Auxiliary heat exchanger
7. Drain tank
8. High delivery pumps of emergency cooling system (E.C.S.)
9. High lift pumps of E.C.S.
10. Water tanks of E.C.S.
11. Depressuriser
12. Demineralisers
13. Control volume tank
14. Change pumps
15. Intermediate condenser
16. Intermediate circuit pumps
17. Cooling tower
18. Tower circuit pumps
19. Filter
20. Heat exchanger

Fig. 3 Simplified Schematic of CLEOPATRA Loop

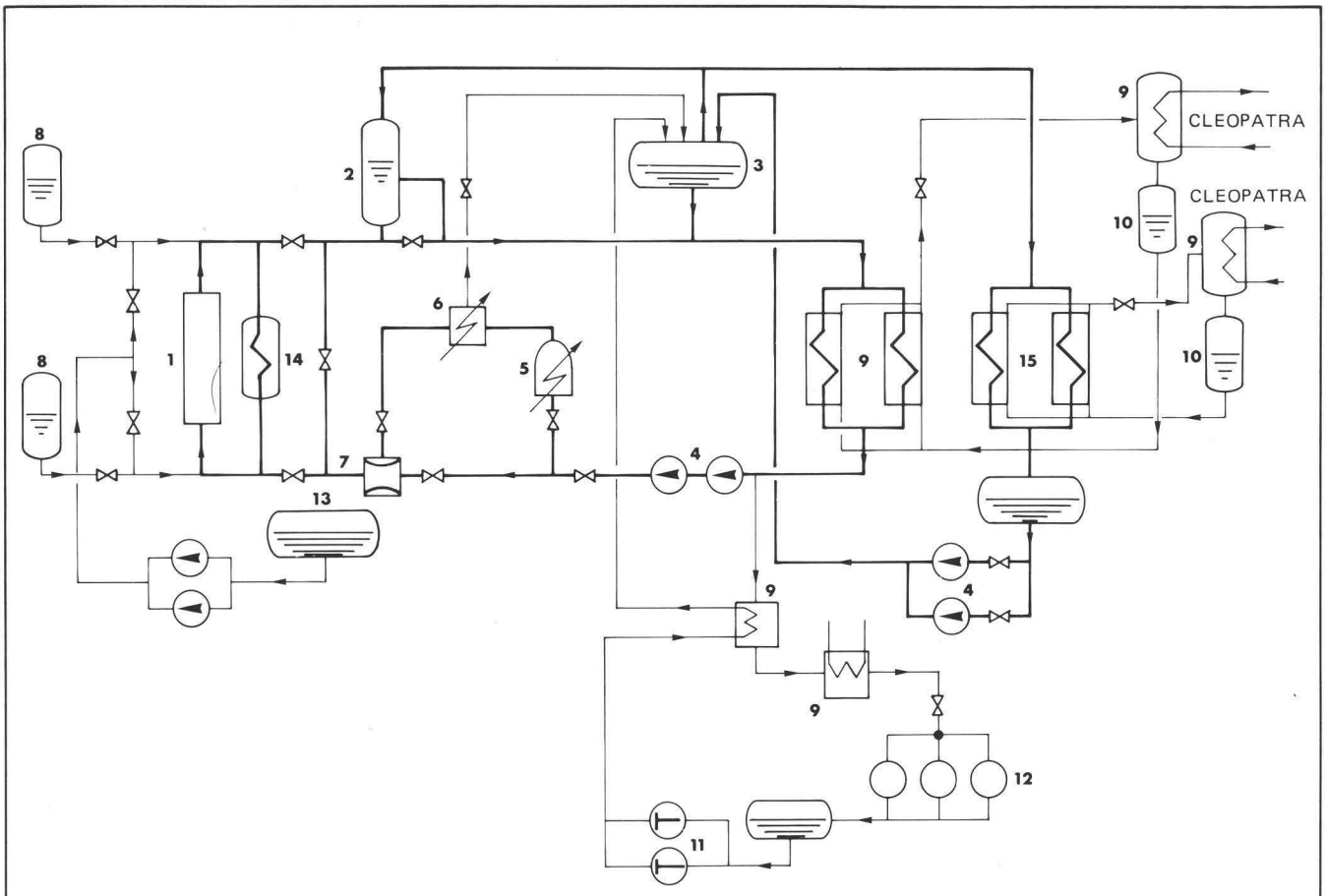


Fig. 4 Simplified Schematic of CABIRIA Loop

Pegaso - A Special Purpose Processor for Smoothing and Peak Elaboration in Mass Spectrometry

S. Amic, F. Sorel, A. Termanini

Introduction

PEGASO (Peak Elaboration and Gain Adaptation for Spectrometry On-line) is used in mass spectrometry with high data output rate to perform a fast data reduction in hardware. This reduction is required since the high data sample rate does not allow a computer to process the information during the acquisition phase and on the other hand the storage of all incoming data is uneconomical considering the redundancy of the information and the amount of data accumulated during long measurement periods. The relevant part of the information in this application is given by the peak position and intensity. The PEGASO processor not only elaborates these values but additionally performs digital averaging and smoothing in order to correct errors introduced by the measurement procedure.

System Description

The mass spectrometer delivers the value of the ion current to a programmable gain amplifier the gain of which is selected by a fast autoranging logic. These two units are required to follow with sufficient precision the high dynamic range of the spectrometer output ($10^5 - 10^6$). The analog signal is converted by an analog/digital converter into a 12-bit binary word. This conversion takes place at a programmable sampling rate given by the minicomputer.

The arithmetic unit during any sampling interval (100 μs) carries out the following functions:

- Division of the A/D output value by the selected gain of the programmable amplifier to recover the original output value of the spectrometer.
- Calculation of the average of a programmable number of sampled signals followed by a normalization achieved through the division by the number of accumulations. This procedure improves the signal-to-noise ratio at low sampling rate having the effect of bandwidth control.
- Smoothing of the spectrum by a least-squares polynomial approximation. The basic idea is to choose a polynomial approximation p(x) to the data function given by the samples $y(x_i)$ in a way which minimizes the squares of the errors.

$$p(x) = a_0 + a_1 x + a_2 x^2 + \ldots\ldots + a_m x^n$$

$$\sum_{i=0}^{N} [\, y(x_i) - p(x_i)]^2 = \text{Minimum}$$

The polynomial p(x) gives a smoth line in place of the noisy data function. A seven-point least-squares parabola is used; since the multiplication factors of seven successive data values are programmable on the front panel it is also possible to use a five-point least-squares parabola or another polynomial approximation.

- Area calculation of smoothed spectrum portions including 7 sampled values.
- Determination of peak value by comparing successive area portions taking account of the sensitivity factor programmed on the front panel, and transfer of the peak value to the computer.

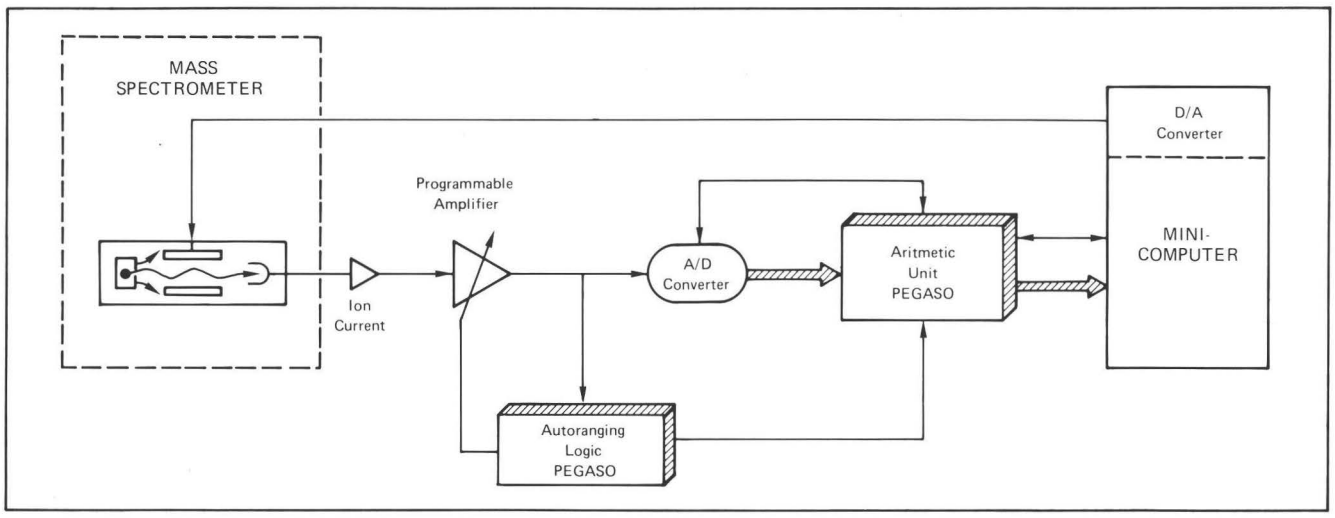


Fig. 1 System Configuration

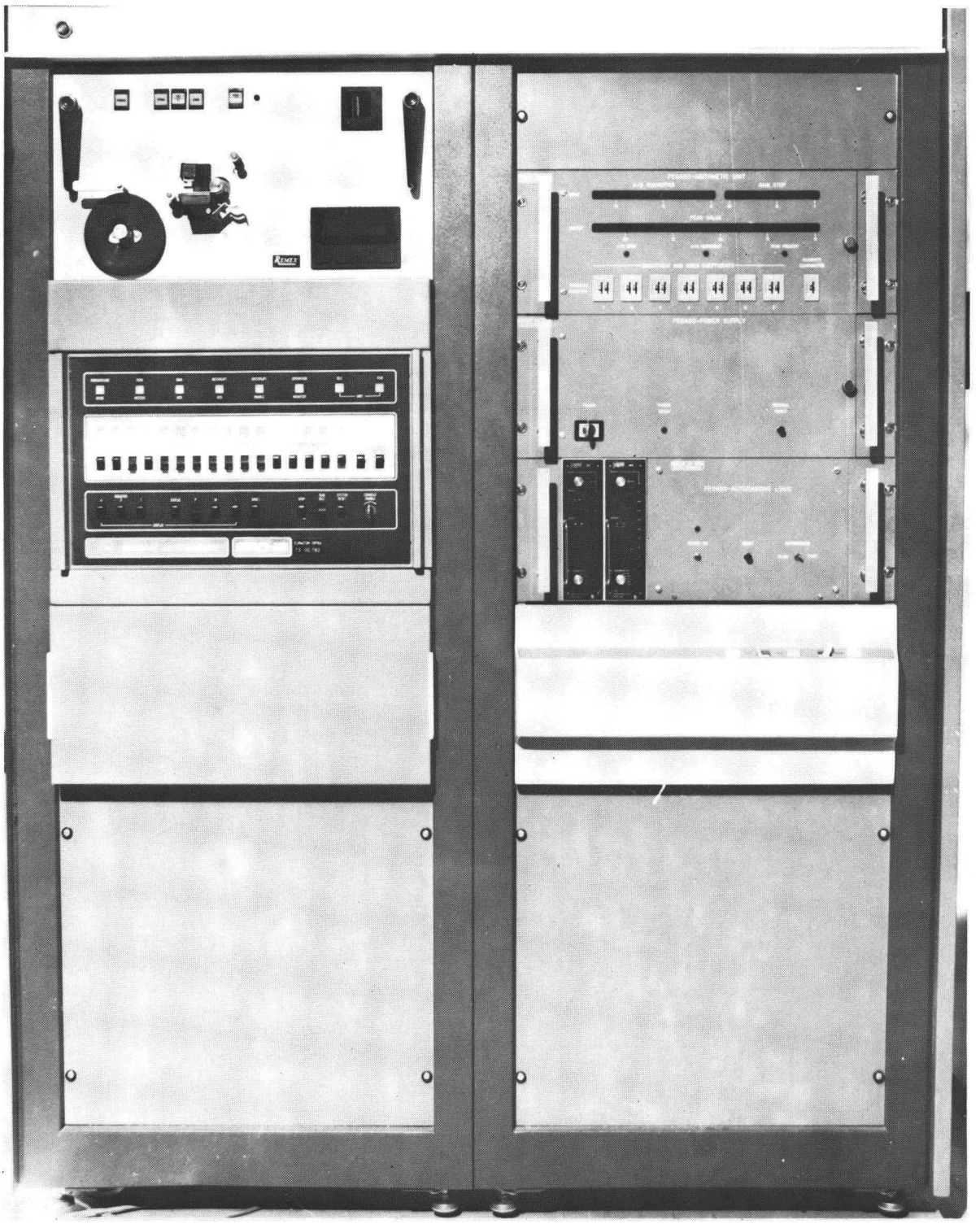


Fig. 2 PEGASO Units and Minicomputer

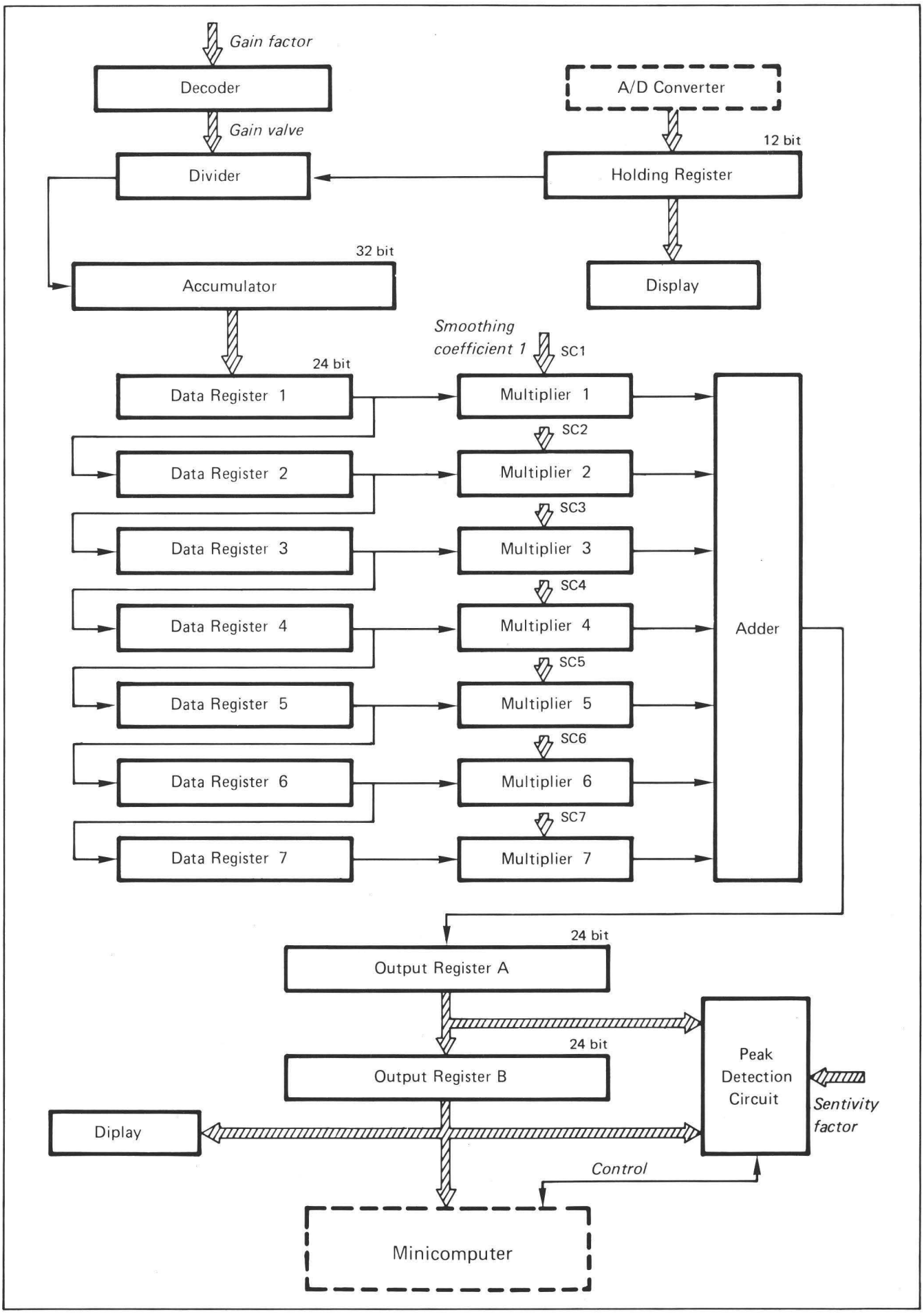


Fig. 3 Block Diagram

Arithmetic Unit

This unit performs the different arithmetic operations such as addition, multiplication and division required for the execution of the mentioned functions. The average register (accumulator) with a 32-bit word length capacity can add up to 128 sampled values.

The smoothing and area calculation are carried out in the following way (see Fig. 3):

- the seven data shift registers are connected in series to store seven successive average values given by the accumulator;
- each value is multiplied in serial-parallel mode by a 2-digit factor selectable on the front panel by thumbwheels;
- the seven resulting products are summed up and the sum is stored in the output register;
- simultaneously with these operations the data is shifted from one register to the next so that at the end of the operations the $(n+1)^{th}$ data replaces the n^{th} data;
- the accumulator loads a new value into the first register and a new cycle starts.

Two output registers of 24 bits each are provided; one contains the actual area result, and the other the result of the preceding calculation cycle.

The peak detection circuit now compares the values of these output registers; the comparator accepts only the values which are equal to or greater than the threshold value given by the sensitivity factor programmed on the front panel. If the new area result is smaller than the preceding value, as occurs at the start of the decreasing slope of the peak form, the circuit defines the preceding value as peak value. The circuit generates an interrupt to the computer and transfers the 24-bit peak value in two blocks of 16 and 8 bits to the computer since the word length of the computer is 16 bits.

The Autoranging Logic

The autoranging logic selects the appropriate gain factor in the range from 1 to 1000 in keeping with the output signal of the amplifier. The autoranging mechanism is designed to work both upwards and downwards at high speed in order to be able to follow all signal variations. The selected gain is also communicated to the arithmetic unit.

The output signal of the programmable gain amplifier is sensed by two discriminators; the first has a low threshold to select a higher gain, the second a high threshold for a smaller gain. The two discriminators control an up/down counter the output of which represents the digital gain factor. Since it is necessary to take account of the amplifier settling time, a logic circuit interrogates the discriminators after a programmable digital delay each time the gain factor has changed.

A holding register stores the gain factor transmitted to the arithmetic unit during the operation time of the latter. It will be updated as soon as the arithmetic unit has picked up the new value.

Conclusion

PEGASO is a fully synchronous operating machine. It is able to perform digital averaging, smoothing and peak elaboration (which correspond to 7 multiplications, 7 additions, one division and one comparison) in 34 machine cycles. With a clock frequency of 10 MHz the total execution time is 3,4 μs.

The computer interface (at present to SPC-16) needs only a few control signals and therefore can easily be adapted to any minicomputer model.

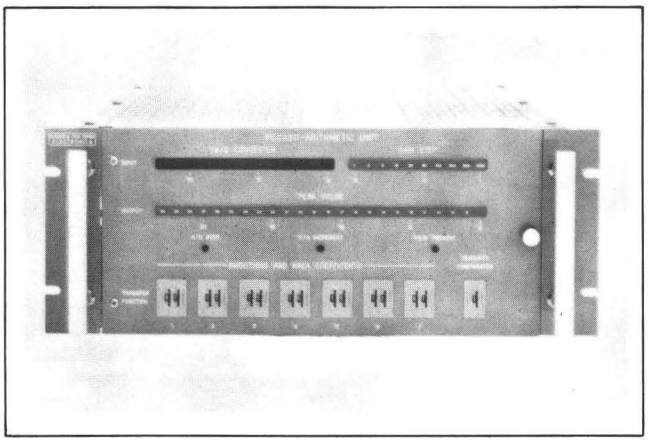


Fig. 4 Arithmetic Unit PEGASO

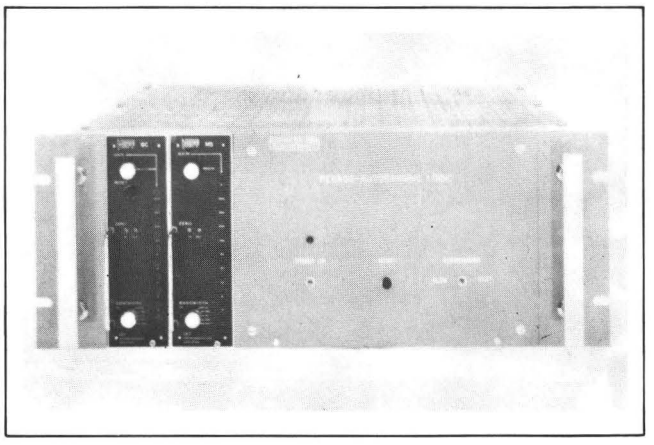


Fig. 5 Autoranging Logic PEGASO and Programmable Gain Amplifiers

On the Interpretation of Acoustic Emission Signals

A.C. Lucia

Introduction

One of the main problems, or perhaps the main problem, in the application of acoustic emission (AE) techniques is the interpretation of the signals. By "interpretation" we mean the extraction of information about the nature and extent of the defect causing the signals, in order to identify and characterize the source itself.

Like many other natural phenomena AE is a random process but, unfortunately, a non-stationary one, because its statistical properties are not constant in time but vary, for example, with variations in the loading conditions to which the material is being subjected.

We know that, from a theoretical point of view, non-stationary data should be analysed by "ensemble" averaging procedures; i.e., by averaging over a collection of sample records at specific instants of time. In fact, non-stationary random processes cannot be ergodic.

Ensemble averaging would require data from a large number of repeated experiments, and, above all, a time non-stationarity would mean that the AE signal recorded during one test cannot be considered representative of the signals which would be found in other similar tests.

However, it is known intuitively as well as from experience that this implication is not necessarily true. For example, if we consider the mean square values of the signals from several different tests of the same type under the same conditions, we would intuitively expect these m.s. value time histories to be similar from test to test, and indeed they will be.

This means that the non-stationary data from one test are at least somewhat representative of the data from other similar tests: hence something similar to an ergodic hypothesis appears justified. In fact the AE process is a special type of non-stationary random process, where each sample record has a common underlying time-varying characteristic. A deterministic factor appears to be present in the nonstationary random process describing the evolution of the AE source during test. This nonstationary random process could be represented by means of a stationary random process affected by a deterministic time-varying parameter. Assuming the time-varying parameter can be identified, the signal from one test should supply the properties of the signals from all other tests.

Special Nonstationary Models

Various types of nonstationary random processes have been considered in the past as "models" for specific physical phenomena, in order to allow an analytical treatment of the phenomenon.

For example, a common model used to describe a non-stationary random process with a time-varying mean square value is given by the process $\{y(t)\}$ where each sample record is of the form:

$$y(t) = A(t)\, x(t) \qquad (1)$$

where $A(t)$ is deterministic and $x(t)$ is a sample record from a stationary random process $x(t)$.
This is the model that we apply to our study of AE signals.

Extraction of A(t) from the Signal

Having hypothesized this mathematical model for the AE process, let us see how it is possible to extract, on this basis, information on the deterministic component $A(t)$.

Up to now, we have carried out 3 types of analysis:

i) mean square value
ii) probability that the signal will cross a given level
iii) probability that the signal will exceed a given level

Analysis of the Mean Square Value

Let us consider the nonstationary process represented by expression (1). The autocorrelation function for this process at the instant t is given by:

$$\varphi_{yy}(\tau, t) = \lim_{N\to\infty} \frac{1}{N} \sum_{1}^{N} A(t)\, A(t+\tau) x_k(t) x_k(t+\tau) \qquad (2)$$

where N is the number of occurrences of the process.
This expression is equivalent to:

$$\varphi_{yy}(\tau,t) = A(t)A(t+\tau)\, \varphi_{xx}(\tau) \qquad (3)$$

where $\varphi_{xx}(\tau)$ is the autocorrelation function of the stationary process $x(t)$ and as such is independent of time.

If the fluctuations of $A(t)$ are very slow relative to the fluctuations of $x(t)$, then:

$$A(t) \cong A(t+\tau) \qquad (4)$$

For all the values of τ in which $\varphi_{xx}(\tau)$ is other than zero, we can therefore write:

$$\varphi_{yy}(\tau, t) \cong A^2(t)\, \varphi_{xx}(\tau) \qquad (5)$$

Nonstationary random processes of this form are referred

to as being "locally stationary".

We know that the power spectrum is the Fourier transform of the autocorrelation function, thus, in this case, it can be expressed as:

$$\Phi_{yy}(t, \omega) = A^2(t)\, \Phi_{xx}(\omega) \qquad (6)$$

where $\Phi_{xx}(\omega)$, being the power spectrum of the stationary random process $\{x(t)\}$, does not vary with time. Expression (6) means that the mathematical model (1) corresponds to a process having a power spectrum whose geometric form remains constant and whose area varies in time according to the factor $A^2(t)$.

The area of the power spectrum corresponds to the mean square value ψ_y^2, so that:

$$\psi_y^2(t) = \int_{-\infty}^{\infty} \Phi_{yy}(t, \omega)\, d\omega = A^2(t)\, \psi^2{}_x \qquad (7)$$

where $\psi_y^2(t)$ and ψ_x^2 represent the mean square values of y(t) and x(t) respectively. Thus the behaviour of the mean square value of the nonstationary random process $\{y(t)\}$ is equal to that of $A^2(t)$, the ψ_x^2 acting as a proportionality constant.

This statement remains valid as long as the dependence upon time of A(t) is reduced enough, in comparison with fluctuations of x(t), to make relation (5) acceptable. In this case A(t) acts on the power spectral density as an amplification factor (variable with time), which as such, does not alter the frequency content of the spectrum.

Probability that the Signal Will Cross a Given Level

The propability $p_1(\tau)$ that a stationary random process, with normal distribution and zero mean, will have a zero crossing between t and $t + \tau$ is given by:

$$p_1(\tau) \cong \frac{1}{\pi} \sqrt{\frac{2\,[\varphi_{xx}(0) - \varphi_{xx}(\tau)\,]}{\varphi_{xx}(0)}} \qquad (8)$$

where the subscipt 1 in the probability symbol means that it is the probability that there is one and only one zero crossing; $\varphi_{xx}(\tau)$ is the correlation function of the stationary, normal random process $\{x(t)\}$ and τ is small with respect to the periods of frequencies present in the process.

In the case of a nonstationary process, the probability $p_1(\tau)$ will vary with time. The expression (11) can be applied to a locally stationary process of the type y(t) = A(t) x(t).

In fact, if the variations of A(t) are slow with respect to the random fluctuations of x(t), we can presume that, in a given interval of time, the process y(t) will be stationary and characterized by a constant factor $A(t_i, T)$ where T is the interval considered. In the successive interval of time, we can once again suppose the process to be stationary, but characterized by a new factor $A(t_{i+1}, T)$.

With this hypothesis, expanding expression (8) in Mc Laurin series around the origin and for the process (1), we can write:

$$p_1(\tau, t) \cong \frac{1}{\pi} \sqrt{\frac{-\varphi''_{yy}(0, t)}{\varphi_{yy}(0,t)}} \cdot \tau = \frac{1}{\pi} \left[\frac{\int_{-\infty}^{\infty} \omega^2\, \Phi_{xx}(\omega)\, d\omega}{\psi_x^2} \right]^{1/2} \cdot \tau \qquad (9)$$

This is the same result as will be obtained in the stationary case, which means that, with the model we have hypothesized, the probability of a zero crossing between t and $t + \tau$ is the same for the nonstationary process y(t) and for the stationary x(t). This is obvious since the hypothesis A(t)x(t) corresponds to an amplitude modulation of the process, and not to a frequency modulation or a change in average value, in which case we should have a variation of the probability of a zero crossing. As has, in fact, already been observed, the power spectrum of the locally stationary process y(t) varies in the area and not in the form.

This situation changes completely if we consider the probability that the signal crosses a threshold other than zero. It can be shown that for a normal stationary process the probability that a threshold at an arbitrary level L will be crossed is given by[11]:

$$p_{1,L}(\tau) \cong \frac{1}{\pi} \sqrt{\frac{-\varphi''_{xx}(0)}{\varphi_{xx}(0)}} \cdot e^{-\frac{L^2}{2\varphi_{xx}(0)}} \cdot \tau \qquad (10)$$

By considering once again the nonstationary process y(t) defined by (1) and introducing the density $\lambda_L(t)$ of level L crossing, we obtain:

$$p_{1,L}(\tau, t) = \lambda_L(t) \cdot \tau = \frac{1}{\pi} \sqrt{\frac{-\varphi''_{yy}(0,t)}{\varphi_{yy}(0,t)}}\, e^{-\frac{L^2}{2\varphi_{yy}(0,t)}} \cdot \tau \qquad (11)$$

In this case both the probability and the level crossing density vary. Their behaviour is linked, through the autocorrelation function $\varphi_{yy}(0, t)$ appearing in the exponential, to the deterministic A(t) factor of nonstationarity.

It is advisable to remember here that the above-shown expression was obtained under the hypothesis that the signal is locally stationary and has a normal distribution.

It is evident that the level-crossing density is proportional to the value of counts/sec when measured with a trigger level on the counter (or the pulse shaper) equal to the level to which the crossing density refers. Therefore we can find the behaviour in time of the crossing probability by measuring the counts/sec value and its behaviour.

An experimental verification of the exponential behaviour of the level crossing density $\lambda(t)$ can be made by means of counts/sec measurements. The counting rate, evaluated with a given trigger level, can be thought as being proportional to the probability of crossing the same level. We can therefore write:

$$\frac{\lambda_{Lk}(t)}{\lambda_{LO}(t)} = \frac{p_{1,Lk}(t)}{p_{1,LO}(t)} = \frac{C_{Lk}(t)}{C_{LO}(t)} \qquad (12)$$

where $\lambda_{Lk}(t)$ and $\lambda_{LO}(t)$ are the crossing densities for the

level L_k and for a reference level, L_O respectively, $C_{Lk}(t)$ and $C_{LO}(t)$ being the counting rates measured with trigger levels L_k and L_O respectively.

This means that measurements of counting rates allow us to determine the behaviour of the ratio (12), which is theoretically given by:

$$\frac{\lambda_{Lk}(t)}{\lambda_{LO}(t)} = e^{-\frac{L_k^2 - L_O^2}{2\varphi_{yy}(0,t)}} \qquad (13)$$

Figs. 1 and 2 show six diagrams of counts/sec, measured with six different trigger levels, on the signal from a tensile test on a carbon steel compact tension specimen.

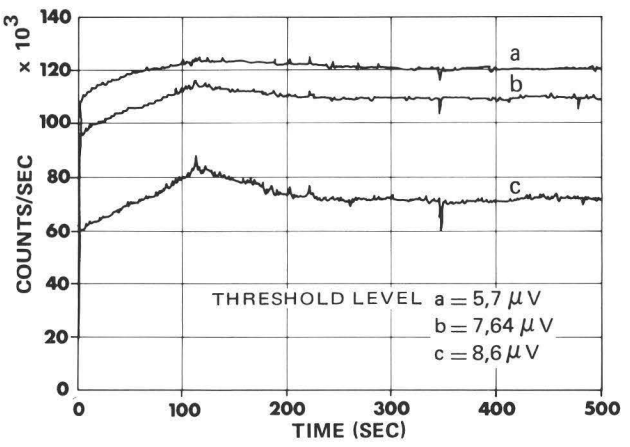


Fig. 1 Test 5.40.3;C.T. Specimen;Carbon Steel;Whole Signal Analysis

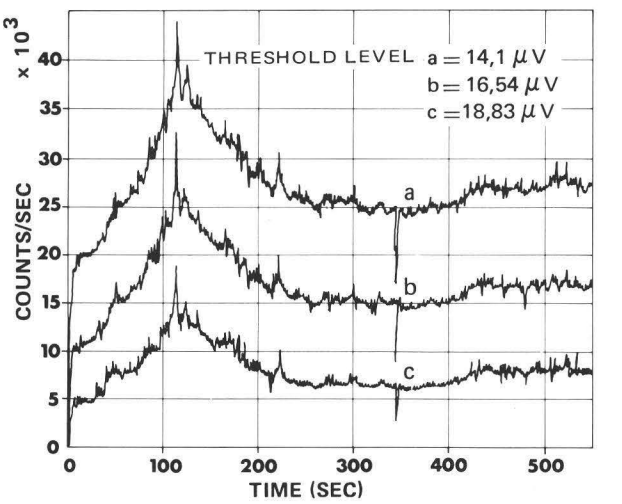


Fig. 2 Test 5.40.3;C.T. Specimen;Carbon Steel;Whole Signal Analysis

Fig. 3 shows the behaviour of the ratio $\lambda_{Lk}/\lambda_{LO}$, plotted against the value of $(L_k^2 - L_O^2)$, at a time t = 200 sec with reference level $L_O = 5.7\ \mu V$.

The values of the threshold levels are referred to the input of the conditioning chain. With linear coordinates (curve a) the diagram is clearly exponential. For further verification, the same points have been plotted in semi-log coordinates (curve b): of course, a straight line is obtained.

Les us now consider further details of the results we obtained by measuring mean square values and counts/sec.

Tensile tests were made on compact tension specimens of two different materials:

i) carbon steel
ii) stainless steel, austenitic, AISI 304

At the beginning of the experiment, there was already a fatigue crack in the stainless steel specimens.

Fig. 4 shows the results obtained with a carbon steel specimen:
Curve a): counts/sec
Curve b): mean square value

After a first almost linear rising area, a maximum is reached corresponding to the first signs of cracking.
Analyses carried out on signals from many other identical specimens gave results quite close to those shown here.

For the measurement of the counts/sec, the signal was sent to a shaper which supplies a pulse of constant amplitude and duration each time the signal exceeds a threshold. This threshold is regulated in such a way that most of the background noise exceeds it. In this case the trigger level was about 3.5 μV, referred to the input of the conditioning chain.
Furthermore, the duration of the pulse given by the shaper is chosen in such a way as to be longer than the average duration of the strong emission bursts in order to reduce the effects of ringing (in this case t = 2,5 ms).

This technique was adopted in order to reduce the influence of the big bursts and extract more information

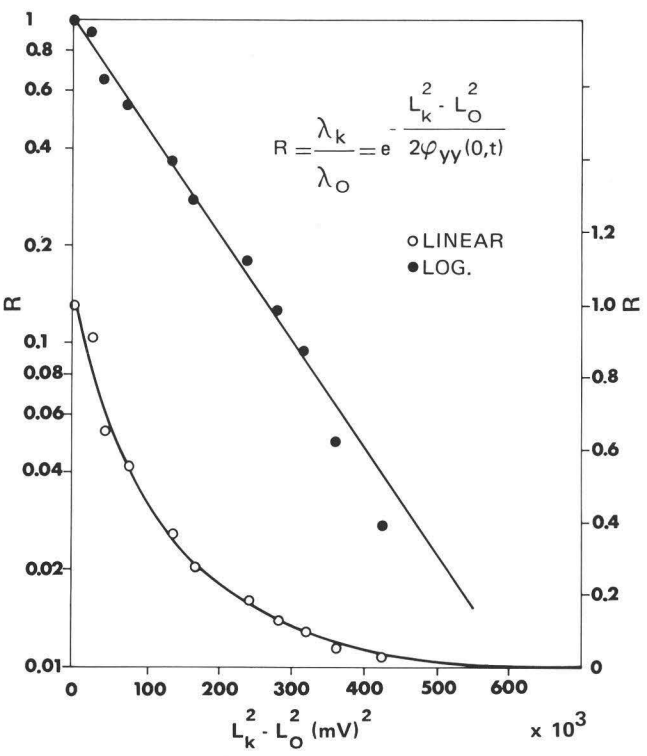


Fig. 3 Test 5.40.3;C.T. Specimen;Carbon Steel;Whole Signal Analysis

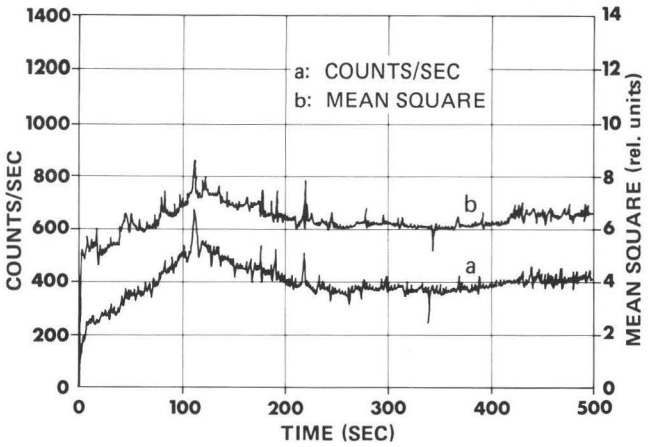


Fig. 4 Test 5.40.3; C.T. Specimen; Carbon Steel; Whole Signal Analysis

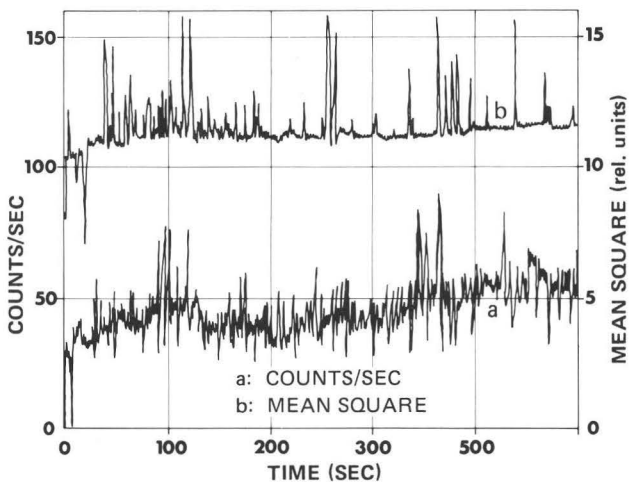


Fig. 5 Test 2.38.3; C.T. Specimen; Stainless Steel; Whole Signal Analysis

from the "continuous emission".

For the stainless steel specimens (precracked by fatigue treatment), Fig. 5 shows the results from test 2.38. In contrast to the carbon steel, the behaviour here is not so easy to interpret. Nevertheless one can see that there is a first linear rising area, with a net slope-variation when the plastic zone is reached (t ≅ 70 sec). A second slope variation, although less evident, can be noticed at t≅ 250 sec, corresponding to the probable time of crack propagation.

This indication of the time of crack propagation agrees very well with results obtained by other people by the methods of electrical resistivity variation.

It should be mentioned here that the time we found for the crack propagation satisfies the J integral method of verification.

Probability that the Signal Will Exceed a Given Level

The third type of analysis that we carried out is that of the "probability that the signal will exceed a given level". The mathematical model we hypothesized expresses the evolution of the AE phenomenon by variations in signal amplitude, so that, if it is sufficiently close to reality, the above-mentioned probability should be able to supply information on the evolution of the AE source.

On the other hand, it is possible to find a mathematical relationship between the crossing dnesity $\lambda_{Lk}(t)$ for a level L_k and the probability $p_{Lk}(t)$ that the signal will exceed the same level L_k.

If T denotes the time of analysis, and $\bar{\mu}$ the mean value of time of sojourn of the random function above the given level, we can write:

$$p_{Lk}(t) = \frac{\lambda_{Lk}(t) \cdot \bar{\mu}(t)}{T} \qquad (14)$$

In this relationship we can see two time-dependent variables, so that we may expect a behaviour perhaps more difficult to interpret but at any rate containing information on the process under test.

Fig. 6 shows the temporal behaviour of this probability, for a carbon steel specimen. The peak is, as in the mean square and counts/sec diagrams, just before the first signs of cracking.

For the case of a stainless steel specimen, Fig. 7 shows a probability behaviour. The two slope-variation instants corresponding to the passage from linear to plastic behaviour and to the crack propagation respectively, are quite clear.

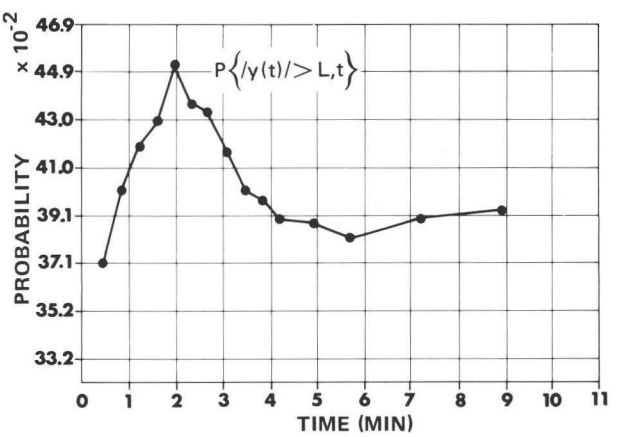


Fig. 6 Test 3.38.5; C.T. Specimen; Carbon Steel; Whole Signal Analysis

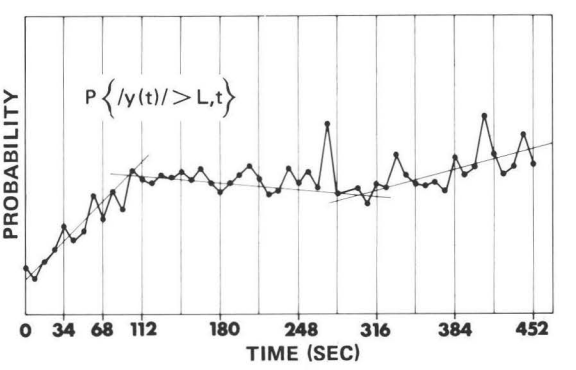


Fig. 7 Test 1.38.1; C.T. Specimen; Stainless Steel; Whole Signal Analysis

It is necessary here to stress the importance, in this method, of finding a length of the time of analysis which is a correct compromise between the necessity of eliminating the random variations and that of following the nonstationary trend.

Some Remarks on the Threshold Level

A few considerations have to be made, at this point, on the value of the threshold level utilized, in analysing the signal.

If the threshold is placed above what is defined as background noise, all the information which the latter contains is ignored. At first in our analyses we wholly disregarded the background noise, in order to take into account only the big emissions, or bursts. This is what we called "discrete emission analysis", where the "continuous emission" was neglected.

The results we obtained in this way seemed able to supply information on the beginning of cracking whereas no information was supplied as regards the evolution of the phenomenon between the commencement of the load and the instant of propagation or formation of cracks. That is to say, by this type of analysis it seems impossible to discern that deterministic behaviour which would appear to be more useful to us. For this reason we decided to carry out analyses on the whole signal, adopting a threshold level lower than the background noise in order to take most of it into account as well. In particular, we wanted to extract from the noise the continuous emission which, though difficult to emphasize at least in the types of experiment carried out by us, is certainly detectable with appropriate methods of signal analysis.

We have seen the results obtained by the analysis of the "whole signal", that is by taking the background noise into account as well.

Let us look now at some results obtained, on the same signals, by taking into account the strong emissions only.

Fig. 8 shows the m.s. value of the signal from a test on a carbon steel specimen.

We can see a first area with large emissions probably due to a spurious settling noise of the tensile machine and to situations of local concentration of stress caused by the mechanical treatment of the sample. The linear zone is characterised by a low m.s. value whereas as soon as the plastic zone is reached, the energy of the emissions begins to increase, reaches a maximum and then starts to decrease. The maximum is reached immediately before the crack opens, as can be seen by other methods. But the overall behaviour of the phenomenon from the commencement of loading to the first signs of cracking is not very clear.

Fig. 9 (carbon steel test 3.38) shows a diagram obtained after a narrow-band filtering of the signal, eliminating most of the initial spurious noise.

Fig. 10 concerns a stainless steel specimen (test 2.38). In this case, too, the method provides an indication of the instant when the plastic zone is entered (first peak) and of the crack propagation instant (second peak), but does not succeed in discriminating the deterministic behaviour. The interpretation of this diagram is, however, rather difficult.

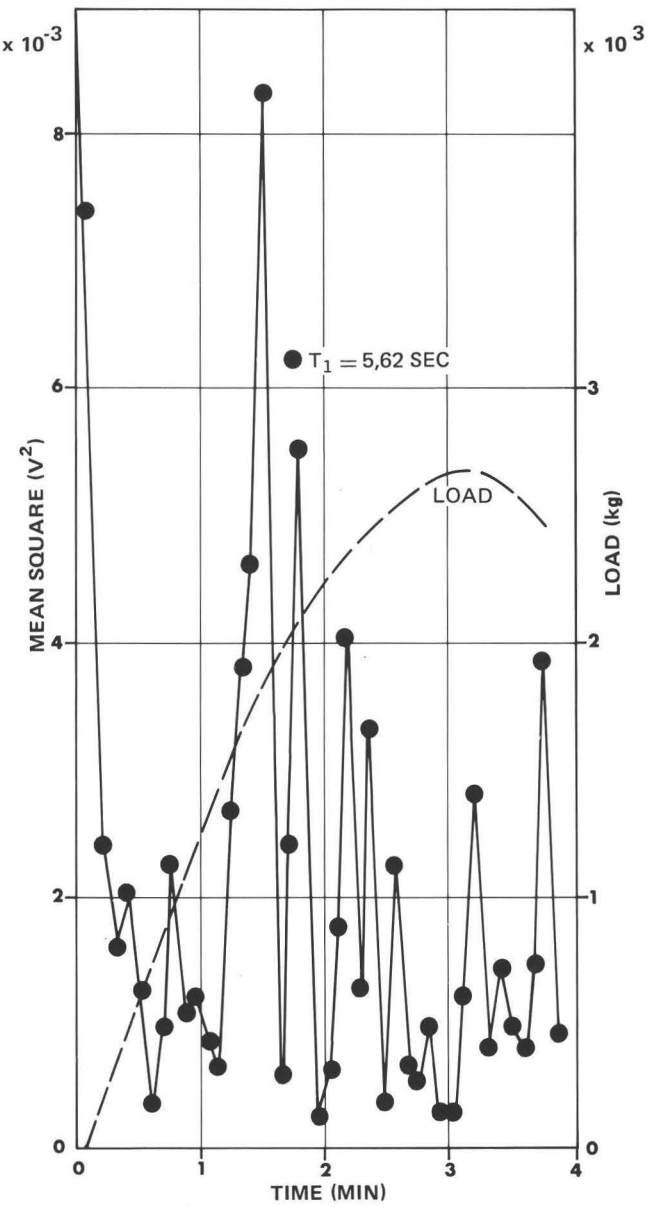


Fig. 8 Test 5.40.3; C.T. Specimen; Carbon Steel; Discrete Emissions Analysis

If we look, for comparison, at the diagram of the counts/sec (Fig. 11), measured with a threshold within the background noise, we can see that the passage from linear to plastic zone and the instant of crack propagation are much more evident.

The same can be said for the m.s. value diagram, Fig. 12. A great drawback in the analysis of the strong emissions only is that, owing to the large difference in the amplitude of the emissions, the contribution from many small emissions to the m.s. value of the signal in a given time-interval can be overwhelmed by the contribution from only one large burst, which could be due not to the evolution of the

process but, for example, to detachment of an inclusion. Another big drawback is that of ignoring the noise and all the signals contained in it; this is one reason why it is impossible to exactly follow the behaviour of the deterministic component of the acoustic emission.

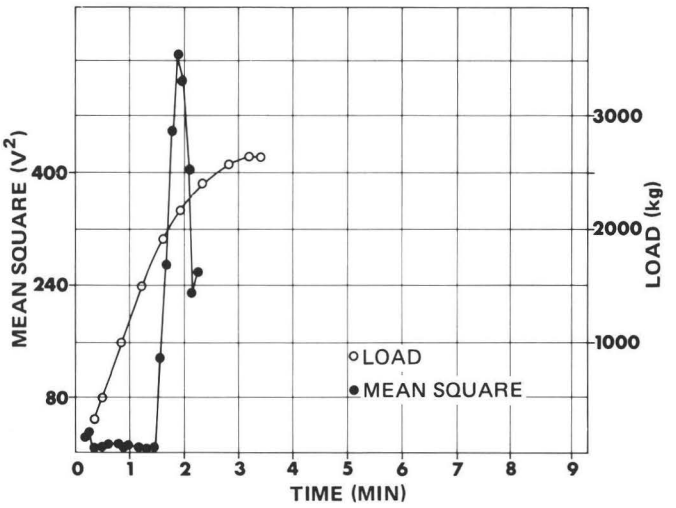


Fig. 9 Test 3.38.5; C.T. Specimen; Carbon Steel; Discrete Emissions Analysis

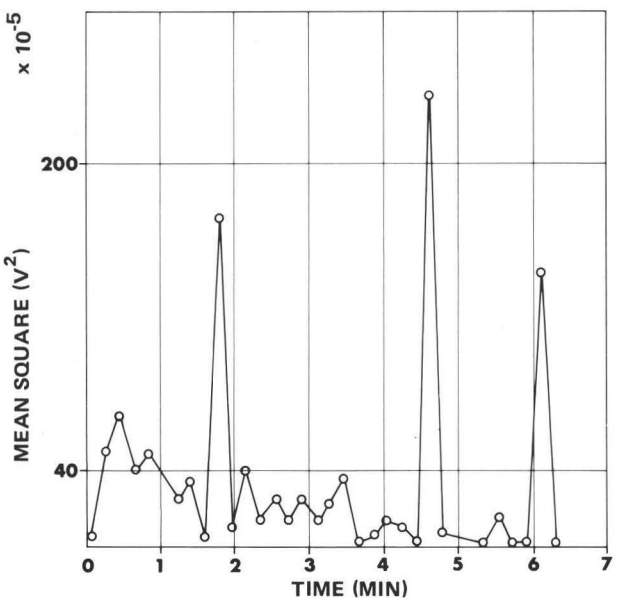


Fig. 10 Test 2.38.3; C.T. Specimen·Stainless Steel; Discrete Emissions Analysis

Conclusions and Perspectives

The conclusion we can draw is that analysis of the whole signal, mainly based on the analysis of the continuous emission, seems to be more promising than analysis of the discrete emissions only; for the latter seems only able to detect dramatic phenomena like the crack opening, whereas whole-signal analysis can supply information on the evolution of the AE source.

It is reasonable to think that by further improving the methodology of analysis, it will be possible to extract the

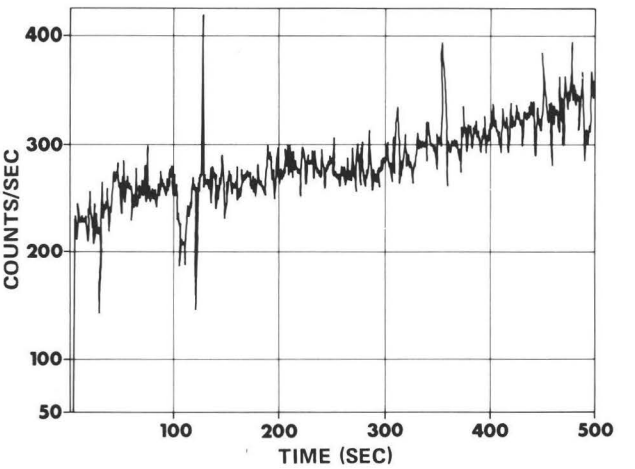


Fig. 11 Test 1.38.1; C.T. Specimen; Stainless Steel; Whole Signal Analysis

behaviour of A(t) more clearly from the signals. The aim is to find a quantitative correlation between A(t) and some meaningful parameter of deformation or fracture mechanics.

On the other hand, the model (1) (which is a model generally used also in statistic descriptions of the damaging processes) represents a process having a power spectral density diagram varying in its area (overall energy instantly released) but not in its shape (frequency range and energy ratios between frequencies). It has been suggested, as a working hypothesis, that this sort of model could be very suitable for bulk deformation processes, while sudden local fractures can contribute to the variation in the frequency content of the signal.

It would be useful to continue in this direction, introducing more sophisticated models which, by also considering variations in the frequency content of the signal, would lead to a better representation of the phenomenon. The fact is that the mathematical model adopted, while agreeing with the experimental results, is nevertheless too simplified and does not take account of variations in the signal frequency, but only of variations in amplitude.

A mathematical model which takes into account the possible frequency variations as well can be constructed

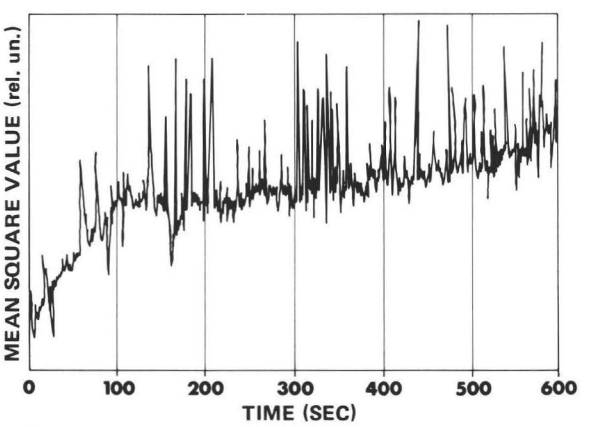


Fig. 12 Test 1.38.1; Whole Signal Analysis; Filter: 100 ÷ 200 K Hz

either by using the model already considered and introducing other parameters into it, or by tackling the problem from an entirely new point of view, for instance by using the "random points" theory.

References

1) R.C. MC CARTY, G.W. EVANS, On Some Theorems for a Non-Stationary Stochastic Process with a Continuous, Non Random, Time Dependent Component". SRI Tech. Rpt. No 4 Stanford Res. Inst., Menlo Park, California.

2) Y.W. LEE, Statistical Theory of Communication, John Wiley, New York, 1960.

3) J.S. BENDAT, A.G. PIERSOL, Measurement and Analysis of Random Data. John Wiley, New York, 1966.

4) A.G. PIERSOL, Spectral Analysis of Non Stationary Spacecraft Vibration Data. CR 341, NASA, Washington.

5) A. PAPOULIS, Probability, Random Variables and Stochastic Processes. Mc Graw-Hill, New York, 1965, pp. 485-487.

6) A.A. SVESHNIKOV, Applied Methods of the Theory of Random Functions. Pergamon Press, Oxford, 1966, pp.69-80.

7) A.C. LUCIA, R. BRUNNHUBER, G. REDONDI, Stress Wave Emission Source Location and Characterization by Digital Methods. Second Symposium on Acoustic Emission, Tokyo, Sept. 1974.

8) A.C. LUCIA, G. REDONDI, Acoustic Emission Signal Interpretation. Third EWGAE Meeting, Ispra JRC, Italy Sept. 1974.

9) B. HENRY, Private Communication.

10) R.L. STRATONOVICH, Topics in the Theory of Random Noise. Vol. 1, Gordon and Breach, New York 1963.

11) A.C. LUCIA, G. REDONDI, On the Interpretation of the Acoustic Emission Signals. Second ASME Congress on Pressure Vessels and Piping. San Francisco, June 23-27, 1975.
and ASME Winter Annual Meeting, Houston, Texas, Nov. 30 – Dec. 5, 1975 Paper No. 75–WA/PVP-20.

Automation of Data Processing in Routine Mass-Spectrometry Isotope Measurements

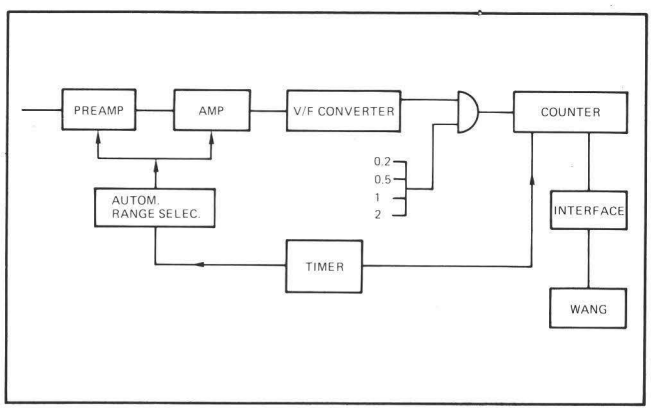
M. Combet, A. Marell, S. Facchetti

Evaluation of analogue recorded spectra requires much time for graphical interpolation, manual reading of interpolated peak-heights and computation of isotope ratios. This is not normally possible immediately after completing a chart recorder scan.

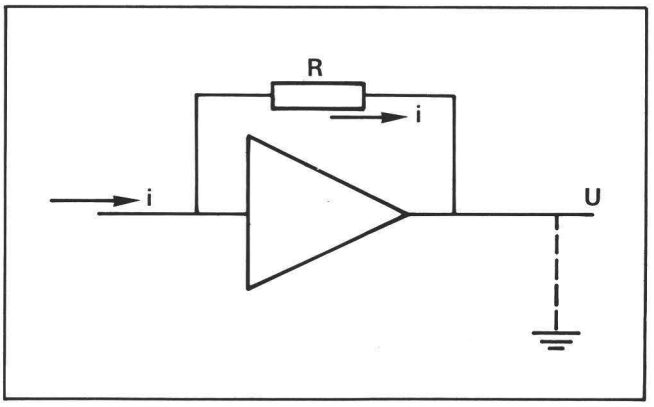
If one can evaluate the spectrum at the time of measurement, i.e. by automatically transferring the measured ion currents directly into the core memory of a desk calculator, the assessment of the quality of the measurement becomes easier and the measurements may be terminated when sufficiently high precision has been attained.

The flow-sheet below shows electronic equipment suitable to measure currents in the range 10^{-9} and 10^{-5} amps from the electron multiplier of a M.A.T. mass spectrometer.

Automatic ranging within 4 ranges and an integrating digital voltmeter with variable integrating time of 0.2 – 2 sec guarantee 10^{-3} precision throughout the input range.



The *preamplifier* converts the input curent into voltage



With an infinite input resistance and low input off-set voltage we have

$$V = R\,i$$

As i is in the range 10^{-9} – 10^{-5} amps we have two possible values for R

i	R	V
10^{-9}	$2{,}5 \cdot 10^{6}$	2,5 mV
10^{-7}		250 mV
	$2{,}5 \cdot 10^{5}$	25 mV
10^{-5}		2,5 V

The current amplifier is followed by the ***voltage amplifier,*** which will match the output of the current amplifier to the input of the voltage to frequency converter.

Three ranges of gain (1, 10, 100) may be selected.

The ***automatic range selector*** consists of two level comparators and a logic circuit that decides the position of the relays for the different ranges.

Integrating Digital Voltmeter – V/F Converter

I.D.V. consists of a voltage-to-frequency converter, the output frequency feeds a counter of six decades.

A gate permits feeding of a counter during a predetermined time of 0.2, 0.5, 1, or 2 sec.

The output numbers are given in scientific notation. The six decimal digits of the numbers (five significant digits + exponent) are stored in an intermediate register and displayed. The values are in the following ranges.

T 0.2 sec from	9999 E O	to	99999 E 3
T 0.5 sec from	2500 E O	to	25000 E 3
T 1 sec from	5000 E O	to	50000 E 3
T 2 sec from	9999 E O	to	99999 E 3

Timer:

The timer controls the operations sequentially as follows; it

- sets the isotope counter, which sets the HT power supply to the value corresponding to the desired isotope,
- sets the automatic ranging,
- starts counting the integrating voltmeter,
- stops counting after the predetermined time
- transfers data into the computer.

Core Memory:

The desk calculator used is a Wang type 700 C. Its core memory is organized into 121 data registers numbered consecutively from 000 to 120.

Registers 000 – 119 are used for storing either program steps or data. Register 120 is only for data storage.

Each programmed operation is represented by a four-digit code which consists of two halves – a higher-order two-digit number and a lower-order two-digit number. A programmed code step occupies two digits of storage, one digit in each of two adjacent registers. The registers of the core memory are 16 digits long. Consequently two registers can accommodate 16 program steps.

The numbers coming from the interface are a maximum of 6 decimal digits and are always integers. Since the mantissa of the registers is of twelve digits one can store two of these numbers in a single register, using a splitting technique. 100 readings (data) can be located in 50 registers. Hence for an isotope measurement of uranium it is possible to make an average of 20 measurements on each single isotope, there being a maximum of 5 U-isotopes.

Program:

The program is divided in two main parts;

a) it addresses the incoming data into different data blocks and recalls them for further treatment after the measurement is finished;

b) it transforms the numbers into real values, i.e. separates the last figure and multiplies the five significant figures with 10 exp. figured in the last position.
It makes the interpolation of the measured peak amplitude, since the ion current may rise or fall during the measuring period.
Finally it calculates the isotope ratios, with their standard and relative standard deviations.

Tables 1 and 2 show the comparison of isotope ratios evaluated manually and by data processor. The samples considered are uranium and neodymium. The total time required is in first approximation

by recorder chart: U = 560 sec. evaluation 30 min.
Nd = 650 sec. evaluation 30 min.

by data processor: U = max 200 sec. evaluation 4 sec.
Nd = max 200 sec. evaluation 4 sec.

Table 1

Intensity ratio value measured by recorder chart			
$\bar{R}$	Int. ratio	σ	$\sigma\%$
$^{235}U/^{238}U$	0.05172	0.00025	0.5

Intensity ratio value measured by data processor				
m/e				
^{238}U	^{235}U	^{235}U	^{235}U	^{235}U
Intensity				
113223	57982	58172	57882	57992
113263	57892	57512	57252	57592
112273	57152	57042	56892	56462
110573	56612	56772	56382	56272
110203	56262	55252	55062	54962
108173	54912	54802	55282	55282
107763	55112	55022	55452	54872
107463	55162	54982	54912	54682
107363	54852	54592	54652	54622
106943	54322	54432	54472	53992
106283	54272	54342	54242	53862
105833	53982	53742	53912	53572
105413	53412	53452	53042	53412
104103	52842	53002	52742	52582
103133	52512	52212	52372	52102
102393	51882	51972	51732	52092
101843	51782	51782	52122	51822
101683	51982	51662	51662	51442
101513	51542	51532	51692	51772
101113	51392	51192	50912	50932

$\bar{R}$	Int. ratio	σ	$\sigma\%$
$^{235}U/^{238}U$	.05101	.00016	.31
$^{235}U/^{238}U$	.05096	.00017	.34
$^{235}U/^{238}U$	.05100	.00019	.38
$^{235}U/^{238}U$	.05095	.00014	.28

$\bar{R}$ = .05098 ±.00003

Table 2

Intensity ratio value measured by recorder chart			
$\bar{R}$	Int. ratio	σ	$\sigma\%$
$^{143}Nd/^{142}Nd$	0.4499	0.0032	0.78
$^{144}Nd/^{142}Nd$	0.8764	0.0064	0.72
$^{145}Nd/^{142}Nd$	0.3036	0.0022	0.72
$^{146}Nd/^{142}Nd$	0.6289	0.0046	0.74

Intensity ratio value measured by data processor				
m/e				
^{142}Nd	^{143}Nd	^{144}Nd	^{145}Nd	^{146}Nd
Intensity				
90603	401432	77683	274902	554302
88733	395602	76663	264592	539202
86823	385542	74573	262252	531162
85653	383222	75133	260932	526152
84453	378172	74853	256532	529602
83753	376712	73673	253282	520192
83803	380312	74173	253702	521602
82743	377042	72943	249852	517232
83233	377802	72373	250912	518202
82253	371502	70933	246432	510202

$\bar{R}$	Int. ratio	σ	$\sigma\%$
$^{143}Nd/^{142}Nd$	0.4504	.0037	0.83
$^{144}Nd/^{142}Nd$	0.8756	.0091	1.05
$^{145}Nd/^{142}Nd$	0.3030	.0015	0.51
$^{146}Nd/^{142}Nd$	0.6215	.0048	0.77

Introduction to Department C

Physics, Chemistry and Materials Science

G.R. Bishop

Department C is composed of the Divisions of Physics, Chemistry and Materials, which names illustrate their disciplinary character and the basic nature of much of the work performed within them. In all three of the Divisions the work content can be recognised as short-term purpose-oriented, or long-term phenomena-oriented, although the proportions of those components differ in each of them. The purpose of the grouping together of these scientific divisions in one Department is more far-reaching than that of satisfying mere administrative constraints, important though these are. The purpose is to accelerate and consolidate the changes in the skills and facilities available within the Department, which are required by the current and future multi-annual programmes. Consolidation is required within those regroupings of scientists and technicians which have reached their critical mass as effective and viable units, with great credit to each of the individuals involved. Those embryonic activities not yet arrived at maturity or a recognisable finality must be reassessed, and decisions made to continue with them or not.

Within the current programme the Department contributes to almost every one of the eighteen objectives. The topics chosen for expanded presentation in this report were selected from thirty others presenting similar features of timeliness or promise which merit the attention of a wide audience. They are to be considered as typical of the much larger flow of results which appear in the recognised scientific journals, in Euratom reports and in the reports made to the Advisory Committees for Programme Management. Since the inception of the current four-year programme the number of publications shows a steady, impressive increase, which indicates the enthusiasm and adaptability of the staff, many of whom were faced with acquiring fresh mental resources and reconciling themselves to different life styles. It must be a goal for the Departmental structure to capitalize as efficiently as possible on these invaluable human assets, and to provide an environment permeated with the most desirable aura to be found in a research laboratory, the scent of discovery.

Physics Division

Whilst all three Divisions were obliged to revise their activities in some measure as a result of the closure of the Ispra-I reactor, the impact was most strongly felt in the Physics Division. For some actions the effects were compounded by a disastrous fire which destroyed apparatus and archives of the group engaged on precise measurements with X-rays and Mössbauer sources. The effort to recovery here has been remarkable, with newly equipped laboratories ready to launch again into studies of lattice imperfections and phase transformations. Otherwise the work in solid state physics has continued across a wide spectrum of actions including point defect properties and radiation-enhanced diffusion in body-centred cubic metals, order-disorder phenomena in face-centred cubic metals and alloys, thin film studies by optical ellipsometry. Through the addition of a high-resolution nuclear magnetic resonance spectrometer working at 270 MHz, the NMR group has added the examination of biological materials to its impressive list of investigations, which include thermally induced polarization, high-temperature relaxation of fluorine atoms in crystals, anisotropic diffusion of small molecules in liquid crystals and diffusion coefficients of hydrogen in transition metal hydrides. The work on biological materials is complemented by the flourishing installation of an electron spin resonance apparatus coupled to a pulsed electron beam delivered from a Van de Graaff accelerator, to study the behaviour of radiation-induced free radicals.

The connection of the Division with neutron physics continues to be upheld by the contributions of detached staff to ILL-Grenoble, who develop and test new types of monochromators for neutron scattering, with ingenious use of crystals having a gradient in the lattice parameter, or a curvature produced by growing oxide or nitride layers on the crystal face. Other groups take apparatus prepared at Ispra for measuring compaigns on ILL beams, phase transitions in ferroelectrics, differential transport of hydrogen isotopes and the energy losses of fission fragments selected by the mass spectrometer Lohengrin.

Rising phoenix-like from the ashes of previous preoccupations are the contributions to the Solar energy objective made by former neutron physicists. Studies are close to completion on the conversion efficiency and spectral response of different photovoltaic converters, and are in course on the development of photon energy converters based on electrochemistry or photobiology for direct or storage uses.

Some reactor physicists have pursued their science on reactors outside the centre making integral cross-section measurements on fast reactor structural materials, and others have shifted their allegiance to the field of reactor waste disposal making measurements of the integral fission cross-sections of the actinides. Finally several theorists have turned their attention to actions in the environment objective, providing analysis for air and water pollution studies in conservative and non-conservative systems.

Chemistry Division

Excellent progress must be reported with the actions executed by the Chemistry Division in the objectives Waste Processing and Storage, Control of Fissile Materials, Standards and Reference Materials, Hydrogen Production, and Protection of the Environment, supplemented by contributions to all the objectives where chemical analysis and know-how is required. Within environmental science is included the multidetection unit for the analysis of organic micropollutants by coupled gas chromatograph and mass spectrometer both under dedicated computer control, which is shortly to be supplemented with a high pressure liquid chromatograph to extend the range of organic substances under examination. In parallel the development of the data bank ECDIN has been accelerated by reinforcing the staff, so that a unique combination of experimental and theoretical activity is being forged. Nonetheless the other actions on chemical pollutants have been pursued vigorously concerning the electric charges of aerosols, the removal of sulphur dioxide from the atmosphere by plants and soil, and the analysis by X-ray fluorescence of lead in gasoline and air particulates. We have under way a comprehensive study of the pathways of lead introduced into the air by internal combustion engines, which depends on the introduction, in the refining stages, of special lead with an isotopic ratio identified by mass spectrometry techniques. Several difficult ion source and control problems have been solved prior to launching the extensive sampling campaigns.

Before leaving environmental science we must mention the measuring campaigns on air pollutant dispersal, which used chemical tracers and studies of the photochemistry of air pollutants. Another heavy metal pollutant to receive attention is mercury occuring in various matrices, which is detected and assayed in an atomic fluorescence spectrometer.

For hydrogen production by thermochemical splitting of water, data have been collected for cycles based on the decompostion of HI and in the Fe-Cl family. Within the Waste Processing objective attention was concentrated on pyrochemical methods for head-end treatment, and on actinide separation by solvent extraction and ion exchange methods. The latter studies have been made on simulated solutions reinforced by explicit radiation damage experiments, but preparations are under way to adapt some hot cells available elsewhere in the Department which are necessary for extending the work to real waste solutions. An extensive analysis of waste disposal hazards by the concept of barrier efficiency has been made, and indicates the areas of ignorance on which much new work remains to be done.

Materials Division

The work of the Materials Division is an intimate blend of basic and applied research with the former on occasion extending through several years before the applications are resolved. Much-esteemed investigations of heat pipes are in this class, where the principles are now applied to the fine control of temperature in isothermal enclosures; the same group applies its skills to the practical problem of measuring the thermo-physical properties of core melts. A considerable expertise in the use of ultrasonic techniques for seals on fuel elements in the Safeguards objective is polished

into an activity of standardization of the equipment used in many other fields, for instance in medicine as aids to diagnostics, therapy and real-time surgical intervention. Contractual work on vacuum brazing and composite thermocouples reflects past interests of the same group who show a capacity to appreciate fundamentals beneath the short-term objective.

Composite materials receive extensive study by phase dispersion or unidirectional eutectic cooling techniques. Again the work has practical results in demonstrating how to tailor mechanical properties to defined needs, or to illustrate the connections between material properties at the microscopic and macroscopic levels. Fracture studies have made good progress through extensive use of electron microscopy and stress wave emission, whilst a long-term goal of reaching simultaneous acoustic and microscopic indications of material behaviour seems closer to attainment. Work is completed on the observation of super-plasticity in the electron microscope, and on deformation-induced cavitation in AISI 310 stainless steel. We link such studies more closely with the stress engineer examining the practical problems of structure loading in reactor assemblies, by developing codes such as the successful EURDYN for non-linear dynamic finite element analysis. Finally mention must be made of an action brought to a successful close, namely the long-term corrosion of zirconium alloys in terphenyls. Such work imposes the maintaining of chosen experimental conditions over very long periods of time, requiring stability and continuity of a very high order.

Ways to a Chemical Storage of Solar Energy

G. Blaesser

Introduction

Practically all applications of solar energy require a transformation of the incident radiation into other energy forms. Even in nature the largest part of solar energy is transformed into differences of temperatures and latent heats which cause the circulation of the atmosphere and of the oceans and maintain the cycling of water which is used partly as a source of hydroelectric power. Much more important for our technological civilization, however, is the use of fossil fuels and hence the exploitation of solar energy stored in the form of chemical energy during the millions of years of earth's history. Industrial methods for chemical storage of solar radiation would thus be of enormous importance at a time of shortage of the natural fuel reserves.

All technical applications of solar energy either concentrate the incoming radiation by means of focusing mirrors or lenses in order to generate high temperatures and pressures in some technical system, or else use the radiation energy directly in its natural concentration, which is of the order of 1 kW/m^2 for vertical incidence at the surface of the earth. Concentrating methods permit the use of well-known procedures of chemical engineering; their problems are related mainly to the necessity of precisely tracking the sun with extended mirror arrangements. Also, some of the most important processes of chemical engineering require a continuous supply of energy and cannot be directly adapted to the intermittent availability of solar energy.

In this report we shall consider only methods without energy concentration, which can use a part of the scattered radiation in the atmosphere and which can be operated without tracking devices if one accepts a certain loss (up to about 40%). As nature has already provided a reliable arrangement for the conversion of unconcentrated solar and scattered atmospheric radiation, namely the photosynthetic system of the plants, all artificial systems should be compared as to their efficiencies with the natural system, since one could also use the natural photosynthetic process by selecting suitable plants of optimum conversion efficiency (perhaps further improved by breeding) for the production of fuels. It turns out, however, that even in the best case only about 1% of the incident solar energy is converted and stored in the plant in form of chemical energy [1]. This is related to the fact, that the energy absorbed is used for the synthesis of rather complicated substances, and these reaction cycles entrain losses of energy. Since artificial synthesis of such products by our present chemical technology is even less efficient, the economic importance of natural photosynthesis in times of energy shortage would be primarily the re-replacement of synthetic products by natural ones, as in the case of rubber; in particular, it appears not to be economic to synthesize food (carbohydrates and fats) if there is a shortage of energy. On the other hand one can hardly justify growing plants for mere energy production as long as a sufficient supply of food for all mankind is not assured. A "food-calorie" is worth more (economically and morally) than a "heat-calorie".

In this article we will first discuss the thermodynamic limits to the conversion of unconcentrated solar radiation. We shall then apply these general energy considerations to natural photosynthesis. Finally, we will present general criteria for artificial photochemical systems for solar energy storage and sketch some ideas for their practical realization.

Thermodynamic Limits for Photochemical Energy Conversion

Photochemical reactions generally occur in two steps. Excitation of a molecule M due to the absorption of a quantum of light (primary process – step 1) is followed by a chemical reaction involving the excited Molecule M* (secondary process – step 2). Part of the excitation energy will be stored in the form of the chemical energy of the reaction products while the rest is lost as heat.

We first consider the primary process in which the molecule M absorbs a quantum of energy $E = h\nu$ and thereby passes to an excited state M* which differs from the ground state mainly by a changed electronic configuration. In both states, M and M*, the molecule can perform rotational and vibrational motions without appreciable change of the respective electronic configurations. The energies of these motions are much smaller than the mean energy difference ΔE between ground state and excited state, but their superposition with the main transition gives rise to a broadening of the absorption line in the spectrum into an absorption band which can be analysed in its individual components only by means of highly resolving spectrometers. In this way it is seen that the ground state consists of a number g_0 of sub-states, and similarly that g_1 sub-states contribute to the excited state.

The excited molecule can return to the ground state by emission of a quantum of light or by a "radiationless" transition in which the excitation energy is transformed directly into heat. Thus the excited state has a finite lifetime τ.

In the dark at temperature T there exists a thermal equilibrium in which owing to statistical fluctuations a certain number (A_T) of molecules passes per unit time to the excited state by absorption of heat, while on average an equal number A_T of excited molecules returns to the ground state. Under these conditions the ratio of the mean number $n_1{}^D$ of excited molecules to the number of molecules in the ground state n_o is given by the Boltzmann formula:

$$n_1{}^D/n_o = (g_1/g_o)\exp(-\Delta E/kT) = \exp(-\Delta F/kT) \quad (1)$$

where we have used the definition of the entropy difference between the two states, $\Delta S = k \cdot \ln(g_1/g_o)$, and the expression for the free energy, $F = E - TS$. We also find that $A_T = n_1{}^D/\tau$ (c.f. Fig. 1a).

An irradiation with light of a certain intensity, spectral distribution and direction induces A_S transitions per unit time to the excited state; under stationary conditions a mean number $n_1 = A_S\,\tau$ will be found in the excited state (Fig. 1b), and this number will exceed the corresponding dark value $n_1{}^D$ by many orders of magnitude ($n_1 \gg n_1{}^D$). The irradiation has thus the same effect as an increase of the free energy per molecule (also called chemical potential) by the amount.

$$\mu_q = kT \cdot \ln(n_1/n_1{}^D) = kT \cdot \ln(A_S/A_T) \quad (2)$$

μ_q can be considered as the mean gain in free energy per radiation induced transition; it is in general smaller than the energy of the incident light quanta, since practically every absorption of light by molecules excites molecular vibrations in addition to the main transition, so that a part of the radiation energy is converted into heat. The quantities A_S and A_T can be written in the form

$$A_S = \Omega_S \hat{A}_S \qquad A_T = \Omega_o \hat{A}_T \quad (3)$$

where Ω_o represents the effective solid angle into which the photochemical system can emit radiation and Ω_S the effective solid angle under which the exciting radiation enters the system, while $\hat{A}_S$ and $\hat{A}_T$ are given by integrals over the spectral distribution of exciting and thermal radiation, respectively, weighted with the absorptivity $a(\nu)$ and the quantum efficiency $\phi(\nu)$ (i.e. the number of radiation-induced transitions per absorbed quantum of frequency ν) of the system [2]. In this way we find:

$$\mu_q = \mu_\nu + \mu_\Omega \quad (4)$$

where:

$$\mu_\nu = kT \cdot \ln(\hat{A}_S/\hat{A}_T) \qquad \mu_\Omega = kT \cdot \ln(\Omega_S/\Omega_S) \quad (4')$$

i.e. the free energy obtained by the system as the result of the absorption of a quantum is given by the sum of two terms of which the first one (μ_ν) contains the spectral properties of the radiation and of the system, and the second

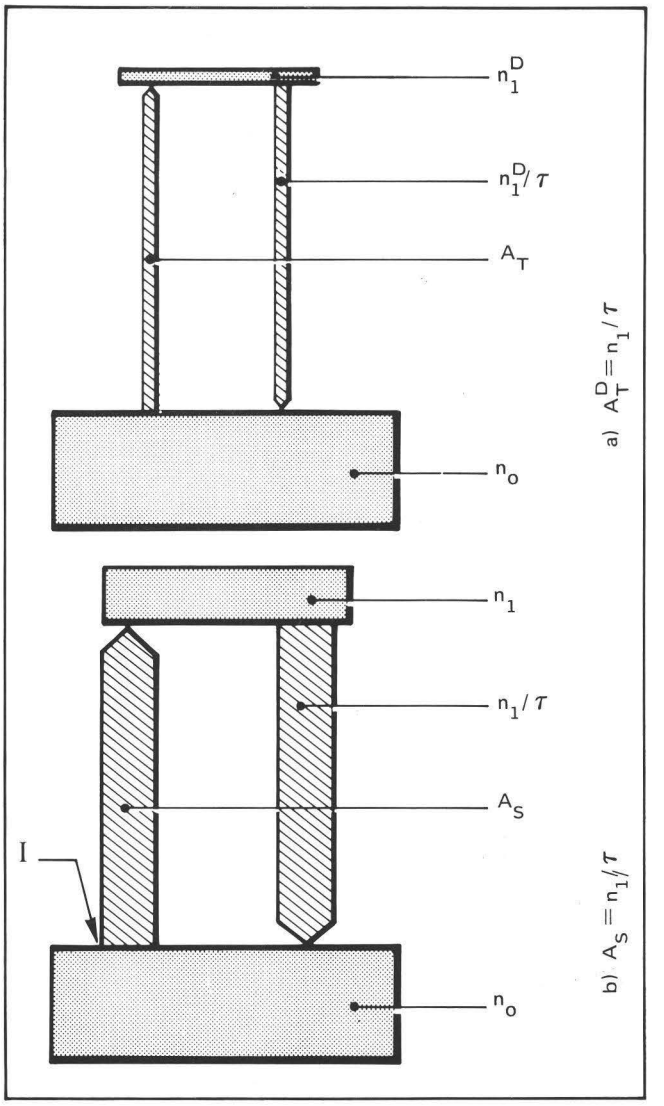


Fig. 1: Schematic representation of the distribution of molecules between ground state (index 0) and excited state (index 1)
a) in thermal equilibrium in the dark
b) in the stationary state under constant irradiation
The width of the errors symbolizes the number of transitions per unit time in the direction of the arrow and the sizes of the rectangles represent the number of molecules in the corresponding state

(μ_Ω) the geometrical effects (solid angle effects). The geometrical "dilution" of solar radiation, i.e. the reduction of intensity in proportion to the inverse square of the distance from the sun, reduces also the "thermodynamic quality" of the radiation in a way similar to the reduction of temperature of a heat source [3]. Conversely, a concentration of radiation by mirrors increases the solid angle Ω_S under which radiation enters the photochemical system and raises in that way not only the radiation intensity per unit surface of the system, but also the "quality" of the radiation. For unconcentrated solar radiation and an isotropically absorbing and emitting system, Ω_S/Ω_o is given by the fraction D of the sky covered by the sun as seen from the earth:

$$D = \Omega_S/4\pi = 0.54 \cdot 10^{-5}$$

this gives for $T = 300°K$:

$$\mu_\Omega = -0.30\ eV$$

The conversion properties of a given photochemical system can be expressed most conveniently by the "conversion efficiency" [4]:

$$\eta = \mu_q \cdot \frac{\text{(number of quanta absorbed per unit of time)}}{\text{(radiation energy incident per unit of time)}} \qquad (5)$$

For a monochromatic radiation and a photochemical system which absorbs completely at that particular frequency ν the incident radiation energy is equal to $h\nu$ times the number of quanta absorbed, so that in this case

$$\eta = \mu_q / h\nu$$

On the other hand, if the radiation source can be considered as a black body of temperature T_s (as it is the case for solar radiation, with $T_s = 5800°K$) then the total radiation energy passing the unit surface per unit of time is given by the law of Stephan and Boltzmann; it is $(\Omega_S/\pi)\sigma T^4_S$ with $\sigma = 5.7 \cdot 10^{-8}$ W/m^2/°K^4. Under the assumption that the quantum efficiency for the transition M → M* equals 1, the number of quanta absorbed per unit time becomes equal to the number of transitions per unit time A_S, so that

$$\eta = (\pi/\sigma)\,\mu_q \hat{A}_S / T_s^4 \qquad (6)$$

The quality $\hat{A}_S = \int \hat{I}_S(\nu) a(\nu) d\nu$ (where $\hat{I}_S(\nu) = (2\nu^2)\exp(-h\nu/kT)$ is the radiation intensity in the Wien approximation which is valid for all visible frequencies ν as long as the source temperatures are less than 10,000°K, and $a(\nu)$ is the absorptivity of the system) will be given here for two limiting cases:

Case 1: narrow line absorber: $a(\nu)$ is assumed to be equal to 1 in a narrow frequency interval $\delta\nu$ centred at ν_o, and equal to 0 outside that interval.

Case 2: broad band absorber: $a(\nu) = 1$ is assumed to hold for all frequencies above a threshold ν_o, while below that threshold $a(\nu) = 0$.

We then find the following expressions for $\hat{A}_S$:

Case 1: $$\hat{A}_S = (\delta\nu/\nu_o) p T_s^3 \exp(-X_s)\, X_S^3 \qquad (7a)$$

Case 2: $$\hat{A}_S = (X^2_S + 2X_S + 2) p T^3_S \exp(-X_S) \qquad (7b)$$

with $p = 2k^3/c^2h^3$ and $X_S = h\nu_o/kT_s$. For $\hat{A}_T$ we find corresponding expressions with $X_T = h\nu_o/kT$ instead of X_S.

In Table 1 numerical values are given for a frequency ν_o corresponding to a wavelength λ_o of 700 nm. In case 1 a line width $\delta\lambda$ of 35 nm was assumed so that $(\delta\nu/\nu_o) = (\delta\lambda/\lambda_o) = 1/20$ – such values constitute already a relatively wide line! The other parameters are $T_s = 5800°K$, $T = 300°K$ and $\Omega_s/\Omega_o = D = 0.54 \cdot 10^{-5}$.

One can see that a line absorber has a conversion efficiency which is by at least an order of magnitude

Table 1

	Case 1	Case 2
μ_ν	1.68 eV	1.76 eV
μ_q	1.38 eV	1.46 eV
η	2.8%	27.3%

inferior to that of the corresponding broad-band system.

In the secondary process (step 2) the excitation energy is transferred from the molecules M* to other molecules and thus removed from the primary system. As a result, the equilibrium concentration of the molecules M* at the same irradiation level is reduced from n_1 to n_1', so that $z = (n_1 - n_1')/n_1$ gives the fraction of the (free) excitation energy which is removed from the photochemical system by the secondary reaction. The free energy of the M* molecules is thereby reduced by the amount.

$\Delta\mu = kT \cdot \ln(n_1/n'_1) = -kT \cdot \ln(1 - z)$;
it thus has the value

$$\mu = \mu_q - \Delta\mu = \mu_q + kT \cdot \ln(1 - z) \qquad (8)$$

Consequently, the free energy ϵ removed from the system M* per quantum absorbed is given by $\epsilon = z\mu$, where, in accordance with eq. (15), μ has to be considered as a function of z. ϵ has a maximum for $z = z_m$, where $(d\epsilon/dz)_{z=z_m} = 0$. It is thus found that

$$z_m/(1 - z_m) - \ln(1 - z_m) = \mu_q/kT \qquad (9)$$

For $z = z_m$, we then have $\mu = \mu_m = kTz_m/(1 - z_m)$. z_m can easily be determined from eq. (16) by means of iteration. For $\mu_q = 1.47$ eV and $T = 300°K$, for example, we find $z_m = 0.982$, i.e. about 98% of the primary free excitation energy is channeled into the secondary process in the optimum situation. The corresponding reduction in chemical potential then amounts to $\Delta\mu = 0.10$ eV, i.e. we obtain $\mu = 1.37$ eV.

In more physical terms the optimization expressed in eq. (16) can be described as follows. If the fraction z of the excitation energy is to be removed from the system M*, this system must be brought into contact with another system, S, of lower chemical potential; the difference in the chemical potentials then acts as the driving force for the transition of the energy from M* to S until, in equilibrium, the potentials of M* and S become equal at the new value μ, at which a fraction z of the excitation energy, determined by means of eq. (15), has been transferred to the system S. If a system with low a chemical potential is chosen for S, unnecessarily large amount of free energy is lost in the transition form M* to S. On the other hand, if the chemical potential of the system S is too high, then too large a fraction of the excited molecules M* will return to the ground state M through fluorescence or rationless transitions, instead of transferring their excitation energy to S. The optimum determined by eq. (16) is somewhere between these extreme cases.

Photosynthesis in the Higher Plants

In this section only those aspects of natural photosynthesis are briefly reviewed which are of particular significance for the energetics and as model for artificial systems. Comprehensive accounts of the modern conceptions of the chemical structure of photosystems and the process of photosynthesis can be found in biochemical textbooks, e.g. [5].

The higher plants possess two photosystems, of which photosystem I exhibits a somewhat longer wavelength limit ($\lambda_o \approx 710$ nm), i.e. a somewhat lower threshold energy, than photosystem II ($\lambda_o \approx 680$ nm). Photosystem I can emit electrons on a higher energy level (i.e. it has a reducing effect), while photosystem II takes up electrons (oxidizes) and thus releases oxygen from water. The electrons taken up in photosystem II are fed via intermediate stages ("electron transport chain") to the oxidized chlorophyll (chlorophyll-a_I) of photosystem I, so that this then returns to the initial neutral state (c.f. Fig. 2). The chemical energy released in the individual stages of the electron transport chain (i.e. the difference in the redox potentials) is used in an as yet unknown manner for phosphorylation, i.e. for the formation of energy-rich adenosine-triphosphate (ATP) from adenosine-diphosphate (ADP) and free phosphate ions. By no means all the intermediate stages of this process have been identified; the energy fixation mechanism in the first stages following light absorption in both photosystems is also unexplained to a large extent.

The energy situation is somewhat easier to survey in photosystem I than in photosystem II since in the former about half of the captured quantum energy is used for the formation of a well-defined product, that is, for the formation of the reduced form, NADPH, from the oxidized form, NADP*, of the nicotinamide-adenine-dinucleotide phosphate. The potential for this electron transition is in the region of -0.32 V, while that of the electrons in the initial state (ground state) of the chlorophyll (CHl-a_I, also called P_{700}) amounts to $+0.43$ V. The final result is thus that photosystem I provides a storage of light energy in the form of chemical energy at a value of 0.75 eV per quantum. From our estimations in the preceding section, however, it could be expected that, of the 1.75 eV quantum energy corresponding to the threshold, about 1.35 eV could be stored in the form of chemical energy. Now, the photochemical system of plants appears to be designed for optimum exploitation of scattered light rather than of direct solar radiation, since photosynthesis also occurs when the sky is overcast, and with better conversion efficiency than in blazing sunshine. Consequently, a value one order of magnitude lower of the ratio $\hat{A}_S/\hat{A}$, and thus a μ value 0.07 eV lower, should be reckoned with. More precise calculations [6], taking into account the detailed spectral shape of the chlorophyll absorptivity, also yield a

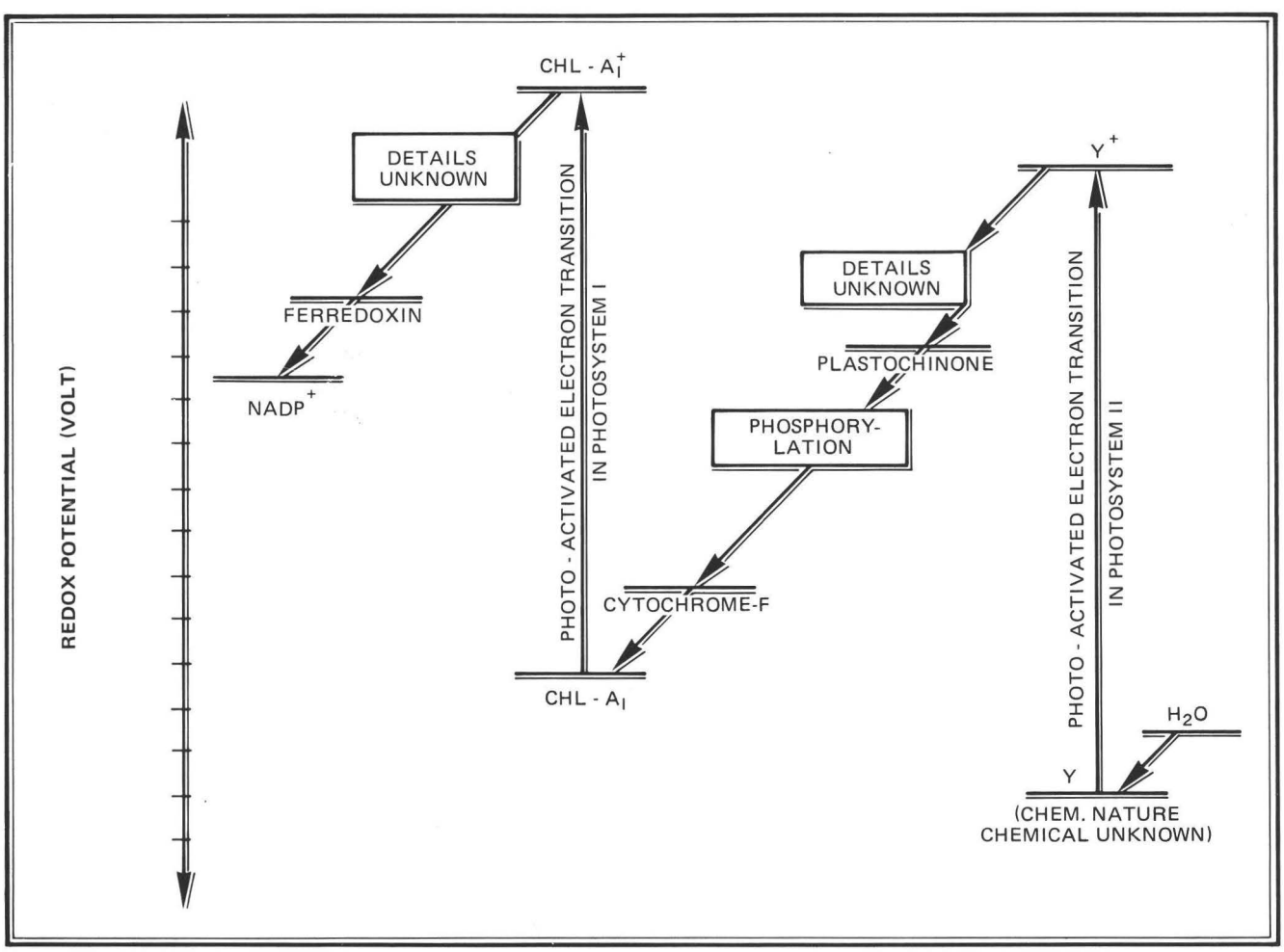


Fig. 2 : Simplified scheme of electron transport in natural photosynthesis

value of 1.26 eV for the available free energy per quantum in photosystem I. Thus about 0.5 eV have been lost on the way from the first fixation of the light energy to the reduction of the NADP. It is also known that a preliminary stage of the NADP reduction is formed by a redox reaction of ferredoxin, which has a redox potential of -0.49 V. Consequently, 0.17 eV have already been used up for the last steps of the electron transport chain, which lead from the excited Chl–q_I to the NADP. Whether the remaining 0.34 eV are also lost in this manner or are used for the formation of further energy rich substances (phosphorylation?) is not yet known. If we accept that only the energy $\epsilon_I = 0.75$ eV stored in the NADP is gained in the light absorption in photosystem I, then the conversion efficiency of photosystem I is equal to $\mu_I = 14.5\,\%$ (using eq. (7b)).

The reactions occurring in photosystem II will certainly not exhibit a better efficiency, so that, ***in toto,*** a storage of about 10-15 % of the incident light energy in chemical form (NADPH and ATP) can be reckoned with. These chemical energy carriers are then used by the plant as energy sources in normal biochemical reactions (dark reactions) and thus are converted back into the energy-depleted forms NADP* and ADP. In these dark reactions, the carbohydrates are synthetised as final products from CO_2 and H_2O (Calvin cycle). Since these dark reactions also occur in a thermodynamically irreversible manner, they are associated with further losses of free energy. If the fact that the plant also absorbs a large portion of the light in substances other than the photochemically active pigments is taken into account, it becomes clear that the total efficiency of the conversion of light into chemical energy, relative to the energy content of the carbohydrates, is only of the order of (at best) a few per cent.

In certain algae, the energy contained in NADPH and ATP is not converted in the carbon dioxyde cycle, but is used for the direct release of hydrogen from water [7]. Nonetheless, the total efficiency of energy conversion in this system also seems to be no better than in the carbohydrate production of the plants.

To achieve substantially better energy conversion, natural photosynthesis would have to be stopped just after the formation of the first energy-rich products (e.g. NADPH), which would then be used in suitable fuel cells as energy carriers, and the resulting energy-depleted forms of the substances used (such as NADP*) would have to be recovered without noticeable losses and fed back into the photosystem.

Even if the practical difficulties associated with such a process would appear to preclude a direct application of the natural photoprocesses for the production of energy, it may be hoped that better understanding of the natural systems will provide hints for the development of optimum arrangements of artificial photosynthetic systems.

A fact of considerable significance is that the photo-active chlorophyll molecules in the leaves of the plants are not randomly distributed but display a lamellar structural arrangement: they are found imbedded between the lipid molecules in the membranes of the thylocoids, which are lens-shaped vesicules of about the order of magnitude of the wavelength of light (diameter ≈ 500 nm). This chlorophyll configuration enables rapid energy exchange to take place between the molecules; in this way, the excitation energy taken up by one chlorophyll molecule on absorption of a light quantum is passed on within a time interval of less than 10^{-9} seconds to a photochemically active centre ("trap"), where the first photochemical secondary reaction (redox reaction) occurs. Only 0.1% of all chlorophyll molecules form photochemically active centres; the other chlorophyll molecules and the other pigments (carotinoids, for instance) serve as an "antenna structure" for these reaction centres. The photochemical reactions lead to a charge separation in the thylacoid membrane, and an electric field is thus formed, during illumination, across the membrane [8], which – as in electrolysis – brings about the transport of ions through the membrane, by means of which, after illumination has ceased, the field decays again. This ion transport seems to play an essential role in phosphorylation.

The chlorophyll structure within the thylacoid membrane is apparently essential for the effective function of photosynthesis. In random form, chlorophyll as a photocatalyst shows only a quantum yield of less than 0.1% (as compared with almost 100% in the natural membrane system) and is thus no better than other dyes of similar structure (phthalozyanine).

Feasibility of Technical Conversion of Solar Energy into Chemical Energy

The most important criteria [9] for a suitable system for exploiting solar energy are:

a) The system must undergo, under illumination, a series of photochemical and chemical reactions of such kind that the final reaction products are richer in energy than the initial products.

b) The quantum yield for the process considered must be sufficiently high.

c) The system must absorb in a broad band of the spectrum, and the threshold energy for the process considered must be adapted to the spectrum of solar radiation at the Earth's surface (i.e. lie in the interval between 1 and 2 eV).

d) If the transfer of energy in the system to the co-reactants takes place by means of a photocatalyst ("sensitizer"), this catalyst should be of a type that will not be used up to any noticeable extent in the course of time; either it should not undergo any chemical change whatever, or it should be completely regenerated in a subsequent reaction (as is Chl-a_I in natural photosynthesis).

e) The initial products of the process must be clearly available in sufficient quantities (as are CO_2 and H_2O in natural photosynthesis).

It is not easy to find a system that fulfils these conditions. The very first condition, that the final products of the photochemical process have to be compounds richer in energy than the initial products, is not met by the vast majority of photochemical reactions.

A process for the photochemical decomposition of water

into hydrogen and oxygen has been studied by HEIDT since 1948 [10]. This process uses a redox system of Ce(III) and Ce(IV) ions in water. The photochemistry of these solutions is strongly dependent on the pH values and on the presence of other ions. Thus in the presence of strongly oxidizing agents (peroxide), oxygen is released under illumination [11]. A measurable release of hydrogen on a larger scale has not, however, been achieved with any arrangement or configuration. It is debatable whether a technically usable output of chemical energy carriers can be attained at all with such homogeneous systems, since the energy-rich substances formed change back too rapidly, through dark reactions into the initial substances.

Rabinowitch [12] suggested that, to avoid such dark reactions, redox systems with two phases should be used, through which the substances formed could be separated from each other. As an example, he studied the photochemical reduction of thionine by complex Co(II) in a water-ether emulsion. Under the action of light, thionine is reduced to leucothionine and the Co(II) complex is oxidized to a Co(III) complex. About half of the leucothionine formed passes over into the ether phase and no longer reacts with the Co(III) complex remaining in the water phase. By separating the ether after irradiation, the leucothionine can be removed from the system and then be reduced back to thionine under energy production in a fuel cell. This system, which still displays a very low conversion efficiency, was only studied to illustrate the idea; the report [13] therefore concludes with the statement that the search for more effective systems and optimum conditions must be continued.

The fact that natural photosynthesis is performed in membranes with an ordered pigment structure suggests that appropriate investigations might be carried out with artificial phospho-lipid membranes enriched in suitable pigments. Considerable progress has recently been made in the "technology" of artificial lipid membranes; it is even possible to create artificial lipid-membrane vesicules of dimensions similar to those of the thylacoids by means of ultrasonic treatment [14]. When such an artificial membrane with a suitable configuration of the electron-emitting pigments on one side and of electron-absorbing substances on the other is brought between two redox systems of different potentials, electric tension develops under illumination in the membrane, which can be used directly as a source of electrical energy or to initiate electrochemical reactions.

The analogy of such a process to the photoelectric effects in the thylacoid membrane is striking, but it may be wondered whether the same results cannot be obtained if the membrane is replaced by a semiconductor with a pn boundary layer, in which – as with semiconductor photoelements – the charge separation occurs under irradiation. It is, in fact, possible to construct interesting photo-electrochemical configurations with semiconductors and aqueous redox systems, with which, if necessary, direct decomposition of the water can be achieved under irradiation [15]. Unfortunately, the condition requiring stability of the semiconductor in contact with the aqueous solution of the redox system considerably reduces the choice of possible systems.

Substantially better possibilities of optimization are obtained if the charge-separating semiconductor system is separated from the electrochemical system, i.e. if a semiconductor photoelement designed for maximum electrical output is connected to an appropriately optimized electrochemical cell (electrolysis cell or accumulator). In this way, conversion efficiencies can be attained which approach the value of 10-15% of the first stage in the natural process and which have never yet been attained with any other photochemical system. Such a system, in fact, fulfils practically all the criteria which were listed at the beginning of this section as essential for the conversion of light into chemical energy. The high costs of both the photo-semiconductor and suitable means of electrochemical energy storage are indeed an obstacle at present to economic exploitation, but it is hoped that such costs will drop considerably as a result of technological progress. In any event, there is currently not even an indication of an alternative, similarly effective photochemical process that could be employed for the utilization of solar energy.

References

1) M. CALVIN. *Science,* **184,** 375 (1974).

2) R.T. ROSS. *J. Chem. Phys.* **46,** 4590 (1967).

3) R.T. ROSS. *J. Chem. Phys.* **45,** 1 (1966).

4) W. SHOCKLEY and H.J. QUEISSER. *J. Appl. Phys.* **32,** 510 (1961).

5) G. GRIMMLER. "Biochemie" Hochschultaschenbücher 187/187a, Mannheim 1969.

6) R.T. ROSS and M. CALVIN. *Biophysical J.* **7,** 595 (1967).

7) J.R. BENEMANN and N.M. WEARE. *Science,* **184,** 174 (1974).

8) H.T. WITT. *Quart. Rev. Biophys.* **4,** 365 (1971).

9) R.J. MARCUS. *Science,* **123,** 399 (1956).

10) L.J. HEIDT and A.F. MCMILLAN. *Science,* **117,** 75 (1953).

11) L.J. HEIDT. *Solar Energy,* **11,** 123 (1967).

12) K.G. MATHAI and E. RABINOWITCH. *J. Phys. Chem.,* **66,** 663 (1962)

13) V. SRINIVASAN and E. RABINOWITCH. *J. Chem. Phys.,* **52,** 1165 (1970).

14) P.G. DE GENNES. Persönliche Mitteilung

15) A. FUJISHIMA and K. HONDA. *Bull. Chem. Soc. Jap.* **44,** 1148 (1971).

Uptake of SO_2 by Plants and Soil

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Introduction

It was estimated by Kellog et al. [1] that 10^8 tons of sulphur are introduced by man each year into the atmosphere. Robinson [2] calculated that 150×10^6 tons of SO_2 were emitted each year, and Meetham [3] concluded from studies in the United Kingdom that of the SO_2 emitted, 14% was deposited by rain or as particulates, 22% was blown out to sea and 64% was removed from the atmosphere through "reaction with surfaces". Disregarding the meteorological or geographical distribution of the gas, it is obvious that vegetation, soils and water surfaces, offer by far the largest "sinks" for its removal.

Plant studies reported in the literature have considered the uptake and fate of sulphur, mostly as the SO_4 ion; relatively little is known on the quantities of SO_2 removed by plants and soils or its fate in them. Dreisinger and McGovern [4] for instance calculated that 14 tons of SO_2 could be taken up per day by vegetation, on a 2000 sq miles area in Canada; Hill [5] calculated that as much as 562 tons of SO_2 could be removed daily by a hypothetical crop of lucerne in a similar area in the U.S. Values for soils will also vary, but up to 89 tons per day could be removed by the same surface of a bare calcareous soil [6].

A review of the information available shows that studies have been made on a wide assortment of plants and soils in a broad range of conditions, and it is at times difficult to extrapolate the values available to forecast for possible situations. It is true that sulphur is an essential element for plant growth and is available in every soil, it is also true that the flora and fauna have adapted through the years to a certain SO_2 concentration in the atmosphere, but with modern developments man is continually introducing more SO_2 into the atmosphere. It is therefore of paramount importance to ascertain the toxic levels beyond which irreparable harm would be done to man's environment and, therefore, to man himself.

The distribution of SO_2 in the atmosphere is influenced by its dispersion and by its physicochemical evolution such as chemical conversion, adsorption and absorption which ultimately will remove it from the atmosphere.

Studies on most of these topics are carried out in a number of European countries and scientific exchanges and collaboration on this broad subject are fostered by a Committee of the European Communities for Cooperation and Coordination of Scientific and Technical research (COST) under a project entitled "Physicochemical behaviour of SO_2 in the atmosphere".

The contribution of the Ispra Joint Research Centre to this project is made through the Chemistry Division in cooperation with the D.G. XII Biology Group, Ispra, and has two main objectives:

a) to determine the uptake of atmospheric SO_2 by plants and soils, as a contribution towards assessment of the half-life of that pollutant, and

b) to establish the cycle of SO_2 in the air-soil-plants-air system.

Since the other parts of the larger COST project consider aspects related to chemical conversion and dispersion of SO_2 and to its adsorption and absorption by water surfaces and building materials, the programme proposed and contributed by the JRC was purposely restricted to studies of absorption of sulphur dioxide by plants and soils.

Material and Methods

The studies are carried out under controlled conditions in order to separate the various experimental parameters with greater accuracy. The experimental scheme consists in placing plants and/or soils in contact with a constant or controlled SO_2 concentration at desired environmental conditions. Three main types of experiments are scheduled:

- SO_2 is in contact only with the aerial parts of plants growing in media of varying sulphur content and varying environmental conditions. In all cases the growth solution or soils are protected from SO_2 contamination;
- SO_2 is in contact only with different soils varying in physical and chemical characteristics including microbian activity;
- SO_2 is in contact both with the plants and with the soils used as growth media.

Test plants will be annuals and perennials, mainly trees, chosen as representative species growing in Europe. Similarly, the soils considered will be of representative types found in the European Community countries.

Plant Studies

The tests are carried out on plants growing in solution or soil, and the following parameters are studied in relation to the presence of atmospheric SO_2: inorganic nutrition, age and development of the plants and their leaves, in particular leaf area and stomatal distribution and movement. The environmental factors to be varied are ambient temperature, relative humidity, wind speed, culture media

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** *The following also contributed to this research:*
X. Dalschaert, A. Hoffmann, I. Johnson, L. van der Eerden, F. Van Zeland.

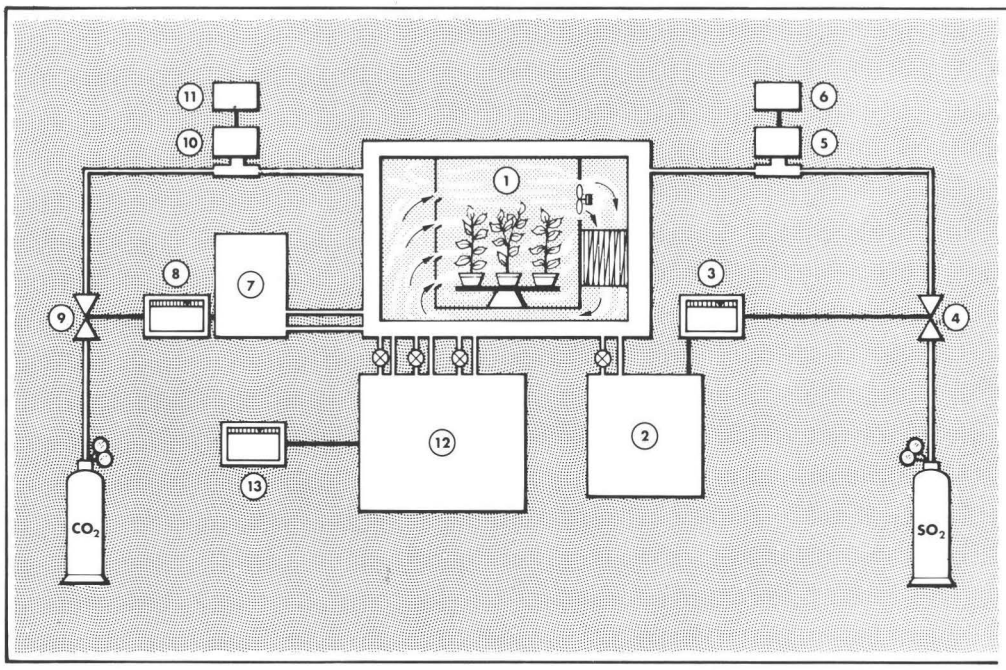


Fig. 1 : Simplified scheme for Plant studies

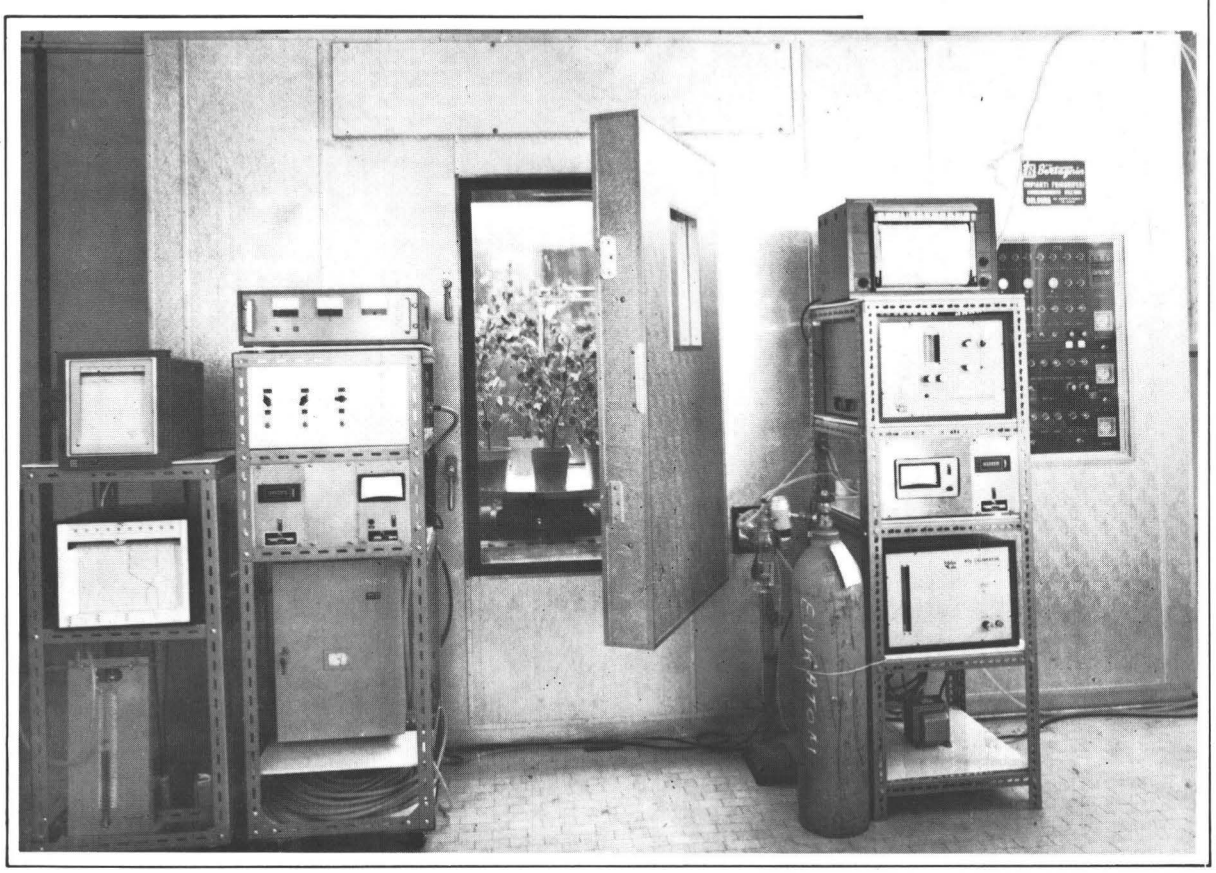
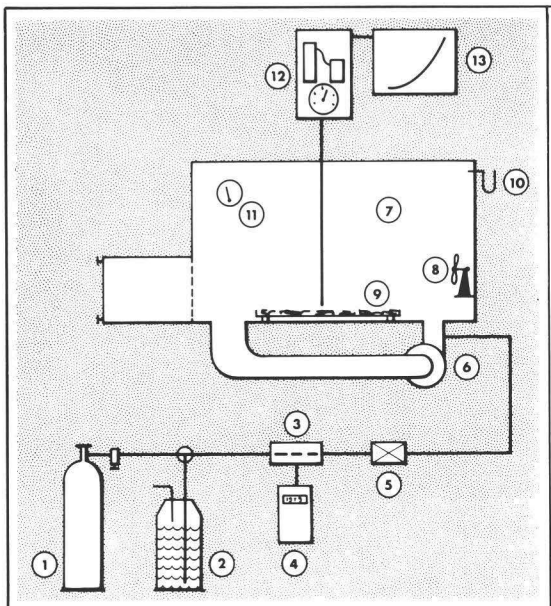


Fig. 2 : Set up for Plant studies. (Nº 12032/66 Sew riproduz. CCR)

and sulphur dioxide and carbon dioxide concentrations in the air. To this effect an installation has been designed and set up. Figures 1 and 2 show the general scheme and a view of the installation.

The installation allows continuous recording and control not only of the SO_2 removed from the atmosphere by the plants, but also of the amounts of CO_2 in photosynthesis. A moisture detector allows us to determine very accurately the transpiration of the plants during the experimental period. Its three measuring points should also enable us to obtain the water vapour profile above a definite leaf surface. Coupled with the measurement of wind velocity by a hot wire anemometer, these data should permit the calculation of the gas transfer from the leaf surface to the bulk air and vice versa.

The walls of the experimental chamber are in stainless steel and the ceiling is made of Plexiglas. Adsorption of SO_2 to the walls and ceiling was found to be directly related to ambient temperature and humidity; when these factors are kept constant, a constant concentration of SO_2 can be



(1) Gas cylinder
(2) Overflow system
(3) Flow meter (Barton cell)
(4) Totalizer
(5) Electrovalve
(6) Centrifugal fan
(7) Experimental chamber
(8) Fan
(9) Soil sample
(10) Manometer
(11) Hygrometer
(12) SO_2 - analyzer
(13) Chart recorder

Fig. 3 : Simplified scheme for Soil studies

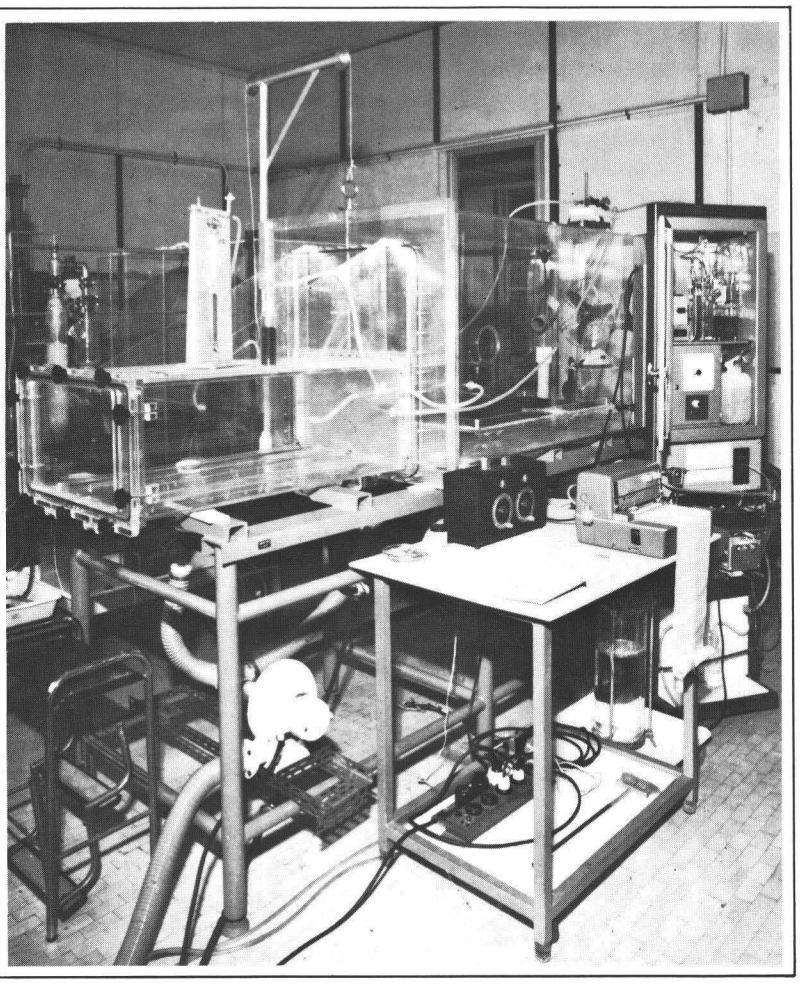


Fig. 4 : Set up for Soil studies. (N° 12032/40 Sew riproduz. CCR)

maintained in the gas-tight chamber, so that when plants are present their uptake of the gas can be measured accurately and the kinetics of this phenomenon ascertained.

In post-treatment harvests a series of analyses will assess the total sulphur, nitrogen, potassium, iron and possibly additional elements found in the various fractions of the plant material. These analyses are necessary because the uptake of the pollutant gas may be influenced to a greater extent by the metabolism of the plants and their chemical composition than by the leaf resistance to gaseous diffusion through stomatal movements.

Soil Studies

The velocity of transfer of SO_2 from the atmosphere to ground is commonly expressed as its reciprocal, the total resistance to transfer, R(z), which may be defined as the sum of three resistances:

$$R(z) = r_a + r_b + r_s$$

where:
r_a = aerodynamic resistance, or resistance to turbulent transfer in the atmosphere
r_b = resistance to transfer, in the boundary layer above the soil surface
r_s = resistance of the soil.

While the value of r_a depends entirely on atmospheric parameters, r_s and r_b depend on the characteristics of the soil and of the soil surface.

Table 1 : Soil characteristics

Name	Symbol	Geographical location	Specific surface area ($m^2 g^{-1}$)	pH (KCl)	Organic matter (%)	$CaCO_3$ (%)	Clay (%)	Exchangeable cations m-equiv(100 g)$^{-1}$
Rendzina	RE	Allonville (Amiens), France	70	7.6	7.6	67.0	17	21
Alluvial gley	PO	Porto Tolle (Veneto), Italy	99	7.4	3	12.3	70	24
Parabrown earth	LO	Allonville (Amiens), France	86	7.3	2.6	0.4	37	18
Podzol	Pd	Hannover, BRD	56	6.4	6.6	0.0	8	17
Terra fusca	TR	Corato (Bari), Italy	144	6.2	5.2	0.0	171	28
Pseudo gley	GL	Ahrzeiler, BRD	53	6.2	2.1	0.2	49	10
Fen	Fen	Emmen, Netherlands	96	4.5	24.6	0.0	6	46

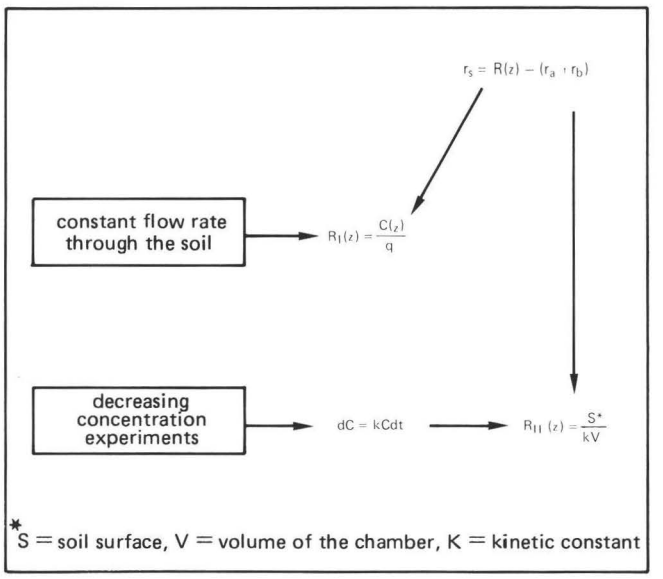


Fig. 5 : Chamber measurements of Soil resistances for SO_2 transfer (present work)

In the present experiments, the influence of soil parameters on the uptake of SO_2 by soils, i.e. their effect on r_b and r_s, is studied under constant environmental conditions, making use of the installation shown in Figs. 3 and 4. The soils chosen for this study represent a sampling of European soil types, and their characteristics are given in Table 1. The theory underlying the two experimental methods employed is shown in Fig. 5. They are respectively based on decreasing concentration experiments and on the introduction of a constant flow of SO_2 into a closed system.

In the constant flow rate experiments a pre-established flux of SO_2 is introduced into the chamber whilst its concentration at a point z is recorded continuously; thus the deposition flux (q) and the total resistance to transfer, $R_I(z)$, may be calculated.

In the decreasing concentration method, a predetermined SO_2 concentration is established in the fumigation chamber where the soil is present but covered by a perspex lid. At time zero it is uncovered and the SO_2 is monitored as a function of time. The concentration decrease being exponential with time, the total resistance to transfer $R_{II}(z)$ is given by the slope of the time concentration line on a semi-logarithmic plot.

A soil impregnated with NaTCM (sodium-tetrachloromercurate) was used as a perfect sink for SO_2, giving $r_s \cong r_b \cong 0$. We were thus able to evaluate the aerodynamic resistance r_a.

Experimental

Plant Studies

Some preliminary studies, carried out with bean plants in a closed chamber where the SO_2 concentration was set by a single initial immission, aimed at determining the relation between the sulphur nutrition of the plants and SO_2 absorption by their aerial parts. They ascertained the capability of the test plants to take up large quantities of sulphur in the SO_2 form, determined the kinetics of this uptake and indicated the importance of the metabolic activity. Results obtained confirmed the influence of leaf development and type on the accumulation and export of sulphur in the various parts following its uptake from solutions. The foliar uptake of ^{35}S-traced SO_2 from the atmosphere was compared for plants grown in a normal or deficient culture medium. Leaves of S-deficient plants accumulated less sulphur than those or normal plants: 20 compared to 230 ppm for primary leaves and 240 compared to 500 ppm for trifoliate leaves. However the average uptake was increased by a factor of 2.5 for bean plants when the total area available was taken into account. The S absorbed from the SO_2-enriched atmosphere reached all plant parts but its concentration varied in the different parts. A field study was carried out to determine the total S accumulated by leaves of green oaks (***Quercus ilex***) growing on the slopes of mount Etna volcano where areas exposed to predominant winds may have an abnormally high SO_2 air content. Results available showed an increase in total sulphur for plants growing closer to the crater and located in the windward direction.

From the values recorded, it appears that no significant difference (less than 1% in total S content) exists between plants growing on the "leeward" side of mount Etna at heights of 900 or 1200 m altitude. On the "windward" side, a difference of 5.6% was found between plants growing at 400 and at 700 m altitude. Comparing leaves of plants growing in a windward or leeward situation one finds a difference of 26% in favour of the windward, very probably due to a large extent to SO_2 present in the air. For wild plants, the total sulphur found in leaves of ***Senecio chrysanthemifolium*** growing on the "windward" or "leeward" sides was for the 1974 growth 3723 and 3012 ppm respectively, an average difference of 23.6% comparable to that of 26% reported above for ***Quercus ilex. Rumex scutatus*** leaves harvested on the "windward" side, the edge of the wind path and the "leeward" side averaged total S contents of 3084, 2744 and 2544 ppm respectively, a difference of 21.2% between the opposite sides of Mount Etna. Despite the drawbacks of this lack of information, and the caution necessary when dealing with field studies, results indicate a clear difference of more than 20% total S content between leaves of ***Quercus ilex, Senecio chrysanthemifolium*** and ***Rumex scutatus*** plants growing in a zone continuously receiving winds with a higher SO_2 content or growing in a much less exposed zone.

The main general programme of research will consider the total uptake by plants annual or perennial, of SO_2 pollutant supplied in an acute or chronic form in different environmental conditions. The influence of the SO_2 on the photosynthetic activity, transpiration rate and mineral uptake of the plants will also be considered. So far, tests have been carried out on beans growing in complete Hoagland nutrient solution, to determine the SO_2 uptake by plants of different age and stage of development. An example of results recorded is shown in Fig. 6 where the SO_2 taken up is indicated as total sulphur present following analysis by X-ray fluorescence. A further confirmation of the difference in uptake by primary or trifoliate leaves,

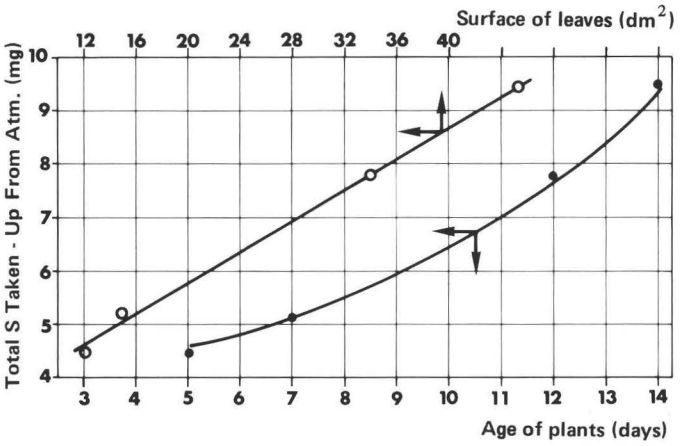


Fig. 6 : SO_2 absorption by beans (phaseolus vulgaris) Experimental conditions: 25°C - 70% R.H. - Light: 40000 erg/cm²/sec - CO_2: 370 ppm - SO_2: 1 ppm SO_2 treatment period: 6 hrs

reported in the ^{35}S studies above, can be seen in Fig. 7 where bean plants were placed for 6 hours at a constant 1 ppm SO_2 concentration and the leaves analysed for total sulphur by X-ray fluorescence.

The studies with annual plants now in progress will, upon completion, be followed by a series on perennials, using trees to assess the capability of vegetation to act as a sink for atmospheric SO_2.

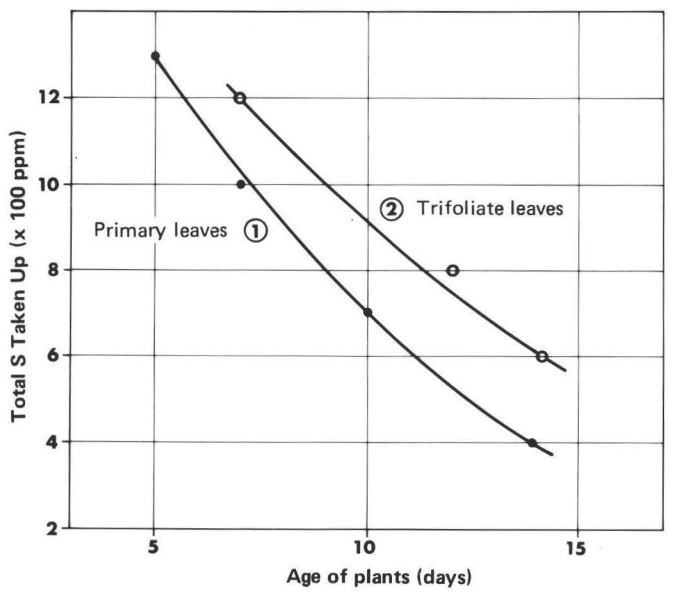


Fig. 7 : Increase of sulphur content of bean leaves after fumigation with SO_2 (1 ppm x 6 hrs)

A short study also relevant here was carried out to determine the effect of SO_2 fumigation on lichens and bryophytes, and its interaction with lead uptake from water solution.

Lichens and bryophytes are considered good indicator organisms with respect to SO_2 in the air; they are also useful in monitoring metal immissions. The possible interaction of these pollutants on the reactivity of these organisms is of particular interest.

The aim of the study was to determine whether SO_2 presence in higher than normal concentrations may alter the ability of the lichens and bryophytes under investigation to take up lead. The response was measured by changes in dark respiration rate (Q_{O_2}) using a Warburg respirometer. The effects of incubation in $Pb(NO_3)_2$ solutions as well as any changes brought about by previous or subsequent treatment with SO_2 were investigated, and of course the reaction to SO_2 fumigation was also considered.

Respiration of lichens and bryophytes was generally increased by SO_2 fumigation. The Q_{O_2} of *Hypogymnia* and *Lecanora conizaeoides* exposed to SO_2 levels of 0.75 ppm for 12 h increased by 30-40%. *Usnea florida*, known to be present only in areas of low air pollution levels, showed no such increase.

The effect of Pb (10 ppm) on dark respiration rate was insignificant though indicating a positive trend; no synergistic effect of Pb and SO_2 was observed.

Fumigation by SO_2 at the 0.75 ppm level for 12 h did not change the metal uptake from 10 ppm Pb solutions during 4.5 h in *Lecanora conizaeoides* and *Hypogymnia physodes.* Further experiments will allow definite conclusions.

Soil Studies

The results of the experiments are presented in the Figs. 8 and 9 and in Table 2. For the constant flux expe-

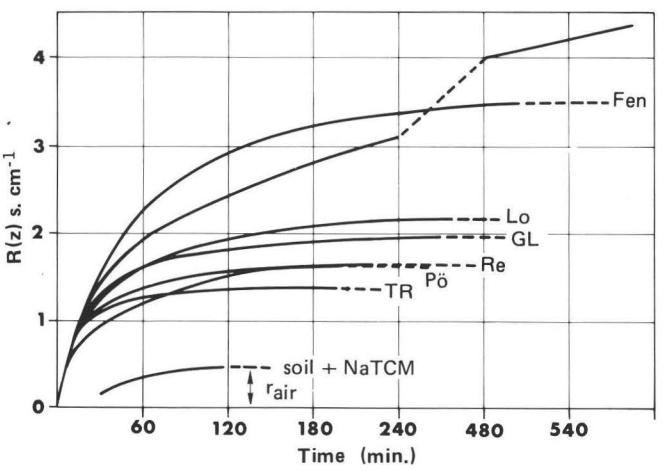


Fig. 8 : Total resistance for SO_2 - Transfer through Soil samples by constant flow method

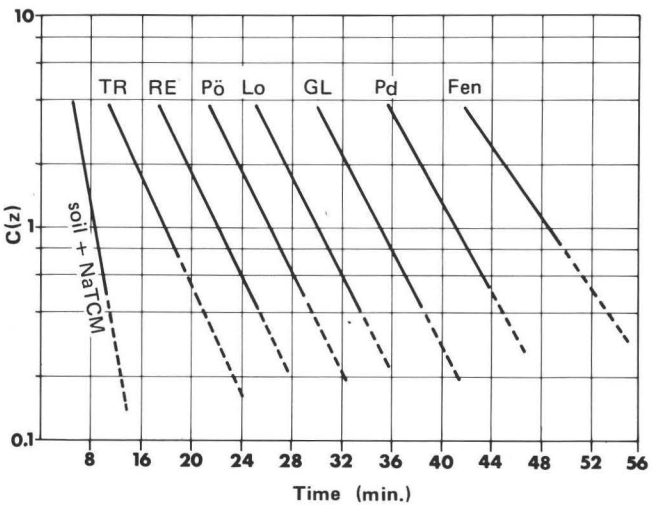


Fig. 9 : SO_2 - Concentration C(z) during decreasing concentration experiments

riments, the total resistance to transfer, $R_I(z)$, is presented as a function of fumigation time in Fig. 8. The function has the form of saturation curves, a constant resistance being reached when the influx of SO_2 equals the deposition flux. The inflow rate of SO_2 used in this series of experiments was of the order of 0.1 $ml.min^{-1}$ and was established from a mixture of 0.1% SO_2 in nitrogen. Three characteristics of thecurves should be noted:

1. A constant resistance was reached fastest with a "perfect" absorbent (soil + NaTCM) i.e. after about 160 min and most slowly with an acid organic soil (fen), after about 500 min, while no equilibrium was reached for a podzol low in clay. The other soils took an inter mediate position.
2. The total resistance $R_I(z)$, increased in the same order, the lowest being soil + NaTCM with R(z) = 0.47 sec cm^{-1} and the highest fen with 3.55 sec cm^{-1}, while an extrapolated value for the podzol would reach 4.8 sec cm^{-1}.
3. The inflow rate of SO_2 being equal for all soils, the concentration at equilibrium of SO_2 for the various soils followed the same order as the resistances, i.e. lowest (0.5 mg m^{-3}) for soil + NaTCM, highest (2.5 - 3.0 mg m^{-3}) for fen and more than 4 mg m^{-3} extrapolated for the podzol.

Table 2 : Comparison of the experimental results

Soil Sample	Water contents %(w/w)	$R_I(z)$ Constant flow experiments	$R_{II}(z)$ Decreasing concentration experiments	$\Delta R(z)$
TR	3	1.36 $s.cm^{-1}$	1.35 $s.cm^{-1}$	0.01 $s.cm^{-1}$
Pö	2	1.61 –	1.53 –	0.08 –
Re	1.8	1.64 –	1.44 –	0.20 –
GL	1.1	1.97 –	1.59 –	0.38 –
Lo	1.5	2.17 –	2.12 –	0.62 –
Fen	3	3.55 –(*)	1.65 –	1.43 –(*)
Pd	1.5	4.8 –(*)		3.15 –(*)
Soil + NaTCM	–	0.47 $s.cm^{-1}$ $R_0(z)$ 0.53 $s.cm^{-1}$		

(*) extrapolated values

For the decreasing concentration experiments, the SO_2 concentrations in the chamber, c(z), plotted as a function of time and for the various soils, are shown in Fig. 9. In this method the duration of the measurements is much shorter than in the constant flux experiments, i.e. 8-16 minutes only. The differences between the resistances $R_{II}(z)$, i.e. the calculated slopes, are fewer and smaller but more or less of the same order as in the first experiment.

Comparing the total resistance values $R_I(z)$ obtained by the two methods and presented in Table 2, one notes that the values of $R_{II}(z)$ derived by the decreasing concentration method are equal to, or smaller than the values of $R_I(z)$. The difference between the two resistances $\Delta R(z)$, given in the last column of Table 2 increases with the total resistance. It is close to zero for soils with a low resistance and reaches a value of 3.15 for the podzol with a high resistance to transfer.

Searching for an explanation for the values of $\Delta R(z)$ one may arrive at the following tentative interpretation:

1. Differences in the aerodynamic resistance between the two methods can be ruled out, as the total resistance values, R(z), obtained for a "perfect" absorber by the two methods are in good agreement.
2. One may infer that the absorption of SO_2 by soil is characterized by two resistances. The first resistance, r_b, is attributed to the absorption process at the soil surface. It is tentatively defined as $R_{II}(z) - R_0(z)$ and it may be shown to be a function of soil pH as represented in Fig. 10.

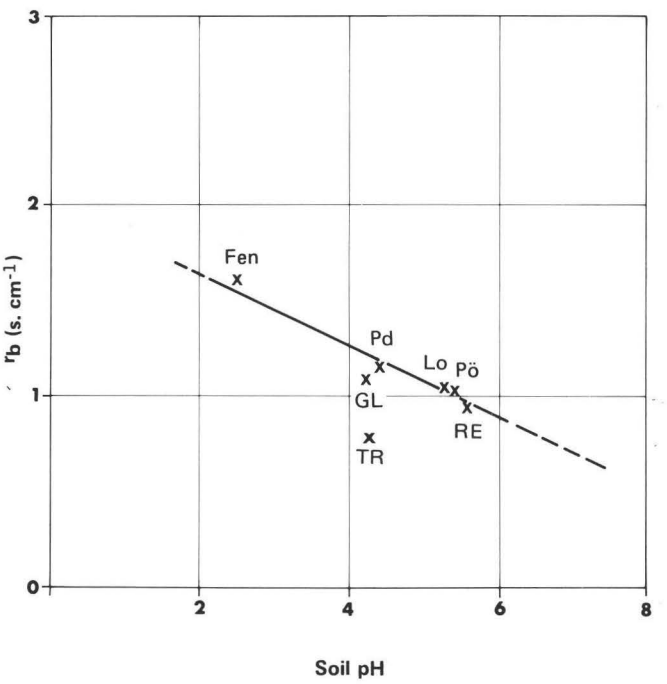


Fig. 10 : Boundary layer resistance as a function of the pH

The second resistance, r_s, is due to the process of diffusion of SO_2 into the soil and it is, again tentatively, set equal to $\Delta R(z)$. In soils with a high sorption capacity like terra fusca, with the fumigation times employed all the absorption will have taken place close to the soil surface leading to a $\Delta R(z)$ close to zero. In soils with a low sorption capacity, e.g. podzol, deeper soil layers were affected by the sorption process. This assumption is supported by the inverse relation between clay content of the soils and r_s, shown in Fig. 11.

In conclusion, a short comparison should be made between the resistance values found by the gradient method [6], and those calculated in the present work. When we designate both r_s and r_b as resistances depending exclusively or largely on soil properties, our values exceed those measured by the gradient method by a factor of 3 or more. Future work should help to clarify the reason for this discrepancy.

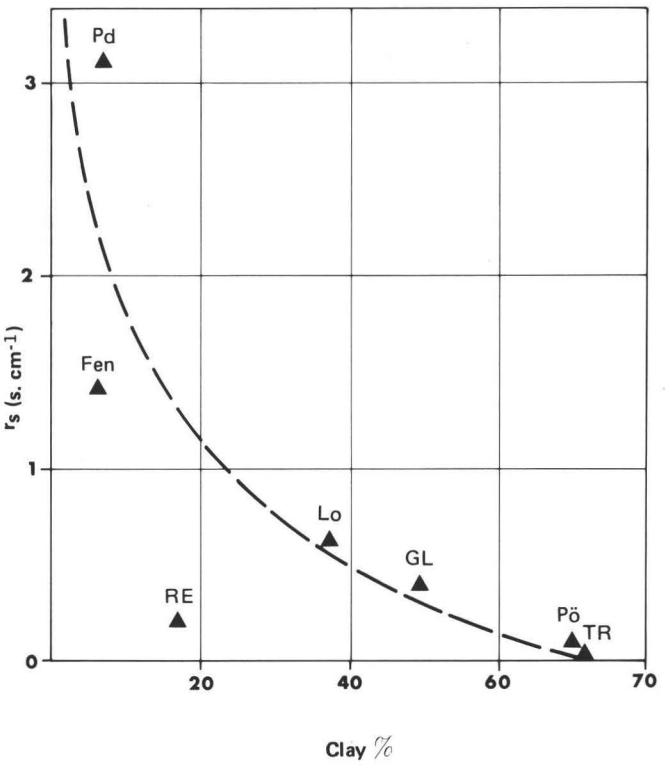


Fig. 11 : Soil resistance as a function of clay per cent

References

1) W.W. KELLOG, R.D. CADLE, E.R. ALLEN, A.L. LAZARUS and E.A. MARTELL, The Sulfur Cycle, *Science* **75**, 587 (1972).

2) E. ROBINSON and R.C. ROBBINS, Sources, Abundance and Fate of Gaseous Atmospheric Pollutants, *Rept. Am. Petrol. Inst.* Stanford (1968).

3) A.R. MEETHAM, Natural Removal of Atmospheric Pollution during Fog, *Quart. J. Royal Meteorol. Soc.* **80**, 96 (1954).

4) B.R. DREISINGER and P.C. McGOVERN, Monitoring Atmospheric Sulphur Dioxide and Correlating Its Effects on Crops and Forests in the Sudbury Area. Proc. Impact of Air Pollution on Vegetation Conference, Ontario, Canada (1970).

5) A.C. HILL, Vegetation: a Sink for Atmospheric Pollutants, *APCA Journ.* **21**, 6 (1971).

6) J.A. GARLAND, Sorption of SO_2 at Land Surfaces – Progress report COST 61 A (1974).

7) A.C. CHAMBERLAIN, Transport of Gases to and from Grass and Grass-like Surfaces – Proceedings of the Royal Society, A. Vol. 290, 236-265 (1966).

8) J.A. GARLAND et al., Deposition of Gaseous Sulphur Dioxide to the Ground. *Atmosph. Envir.*, **8**, 75-79 (1974),

9) E.C. SEIM, Sulphur Dioxide Adsorption by Soil. – Ph. D. Thesis, Univ. Minnesota (1970).

10) M. PAYRISSAT and S. BEILKE, Laboratory Measurements of the Uptake of Sulphur Dioxide by Different European Soils. *Atmosph. Environment* **9**, 211-217 (1974).

Acoustic Stress Wave Emission in Aluminium and its Alloys during Plastic Deformation at Room Temperature

P. Fenici, N. Kiesewetter, P. Schiller

Introduction

Acoustic stress wave emission is being considered in non-destructive testing as a possible tool for early failure detection. The locating of emission sources by triangulation has been fairly well developed and can be applied even in complex structures, but up to now no comprehensive investigation has been made into the possible sources of the emission and the physical processes which give rise to acoustic emission. It is the aim of our investigation to provide information on the origin of the phenomena.

Acoustic stress wave emission was observed during deformation. Starting from the simplest material, a single crystal, step by step structural defects such as grain boundaries, impurities and second phase particles were introduced in the material. The difference in the signals between two consecutive steps could therefore be attributed to the change in structure. It was possible to clarify the way by which moving dislocations contribute to the acoustic stress wave emission in aluminium.

It was further found that grain boundaries in aluminium during deformation at room temperature do not emit acoustic signals and that the presence of second-phase particles strongly alters the character of acoustic emission.

Apparatus and Type of Signals

The signals generated in a material during plastic deformation are in general rather small and can be detected only by undamped piezoelectric transducers. The amplified output signal can then be recorded or elaborated by electronic devices. The block-scheme of the electronic equipment used for our experiments is shown in Fig. 1.

The signal is received by the piezoelectric transducer attached to the head of the tensile specimen (Fig. 2). The preamplified signal passes through an electronic filter which eliminates the background noise of the tensile testing machine and other low-frequency disturbances. This signal goes to a level recorder with an integrating time-constant of 0.1 sec; its indications correspond to the square root of the energy received by the transducer. In parallel to the level recorder there is a second line with a further amplifier which furnishes its signal to a demodulation stage which eliminates the high-frequency content of the signal deriving from the eigenfrequency of the transducer, and leaves only the envelope of the signal. On a multichannel analyser it is possible to count the single bursts originating from the deformed material and to measure their amplitude distribution. The signal can be also registered on a galvanometer displaying the time distribution of bursts during deformation.

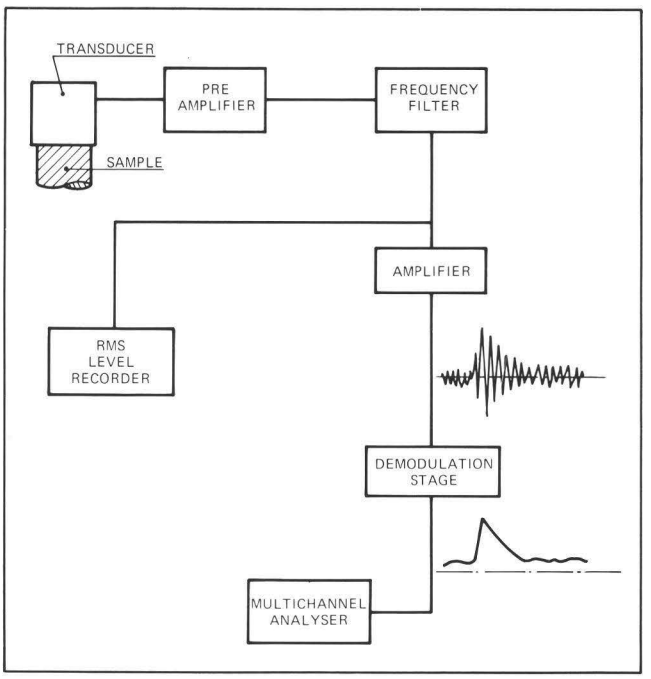


Fig. 1 : Block-scheme of electronic equipment

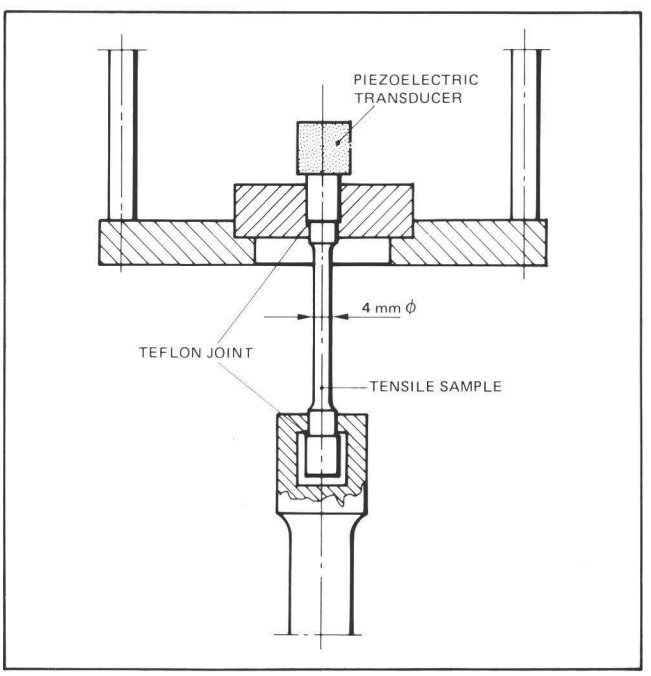


Fig. 2 : Mounting of the specimen in the tensile machine

As anticipated above, the signals arriving from the transducer contain mainly two components, a continuous part (Fig. 3a) and bursts (Fig. 3b). Depending on the materials, and probably on the temperature, the signals emitted during deformation contain the two components in different ways. It is the task of this investigation to determine the possible sources for the different signals.

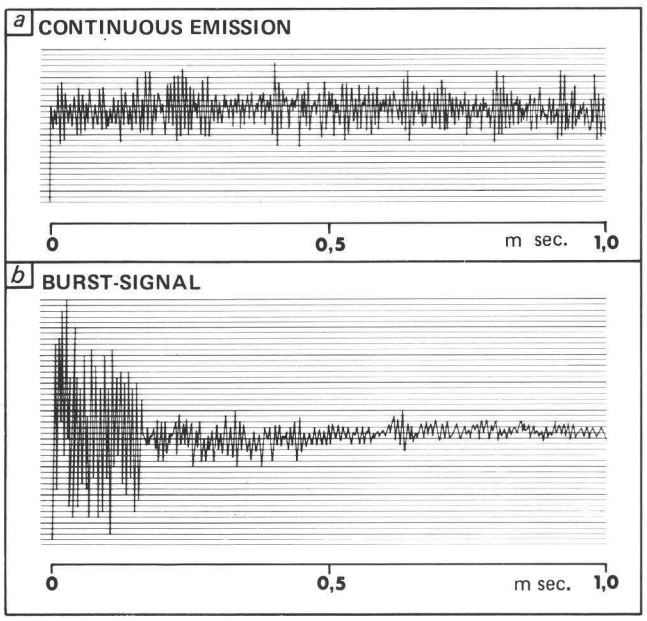


Fig. 3 : a) Example of registration of continuous emission
b) Example of registration of burst emission

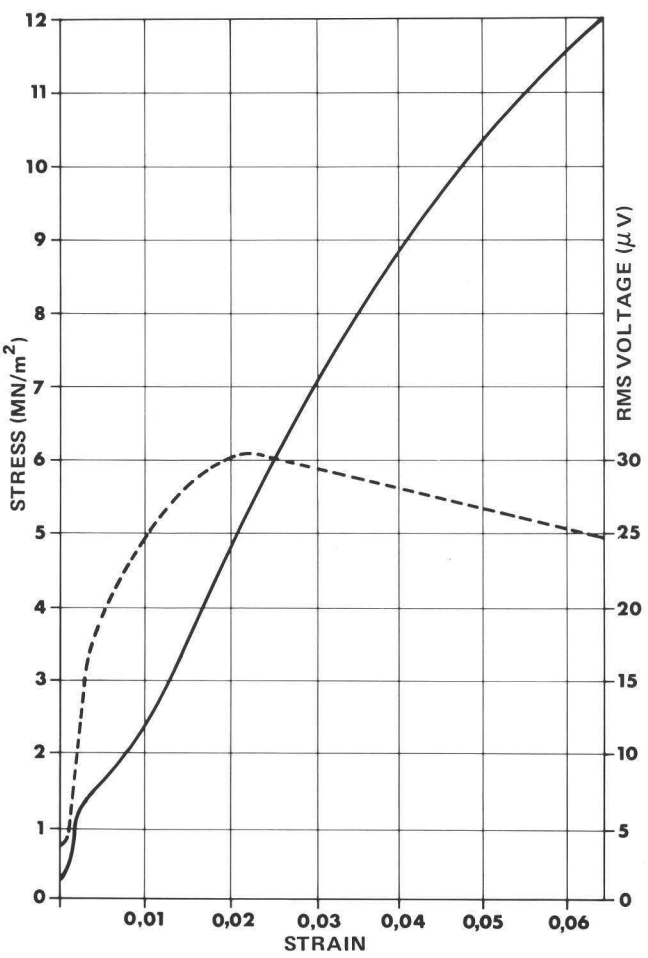


Fig. 4 : Dependence of acoustic emission (---) and flow stress (——) on plastic strain in aluminium single crystals

Results

The phylosophy of these measurements was to start with the simplest material in an alloy series and to introduce structural defects step by step in order to be able to identify the sources of the acoustic signals. Measurements were therefore done at room temperature on specimens of the following aluminium-base alloys:

- pure single crystals;
- pure polycrystals with different grain sizes;
- impure polycrystals;
- aluminium-4% copper alloy in different aging stages;
- eutectic composite alloy Al-Al_3Ni, unidirectionally solidified.

Aluminium Single Crystal (99.99%)

The signals observed in aluminium single crystals with transducers with resonance frequencies of 140 kc and 900 kc do not contain bursts and are of the continuous type only. Emission is only observed during plastic deformation and varies with the plastic strain (Fig. 4). The emission increases very rapidly during the first two stages of deformation, reaches its maximum at the end of stage II and decreases slowly during stage III.

In the experiment shown in Fig. 5 the plastic deformation was interrupted several times in order to prove that acoustic emission appears only during plastic deformation and not during elastic loading or unloading of the specimen. The intensity of the acoustic signals and the value of the flow-stress before and after unloading are exactly the same. As the flow stress is a measure for the dislocation structure in the material, the close relation between emission and flow stress in every part of the deformation curve clearly shows that the intensity of the acoustic emission is related to the dislocation structure.

In Fig. 6 the RMS signal of an Al single crystal deformed at different strain rates is reproduced. The ratio between the signals at high and low velocities is about $\sqrt{10}$, the ratio between the two velocities being 10. This result holds good for both frequencies investigated, i.e. for 140 kc and 900 kc.

Different crystals deformed at different strain rates can be compared at stages of the deformation curve where they have the same flow stress, which means roughly the same dislocation structure.

In Fig. 7 it is shown that the normalized signal ($^{U}RMS/\dot{\epsilon}1/2$) is independent of the strain rate over a very broad range of strain rates. This means that the proportionality between the RMS signal and the square root of the velocity is maintained over a wide range of strain rates, frequencies and dislocation structures.

Pure polycrystals (99.99% Al)

Measurements on polycrystals were introduced in order to determine whether there are signals coming from grain boundaries. At room temperature the emission of polycrystals is still of the continuous type with some burst-signals. The intensity is somewhat smaller than for single crystals (Fig. 8) at the same flow stress. Due to the hardening caused by the grain boundaries we cannot observe the

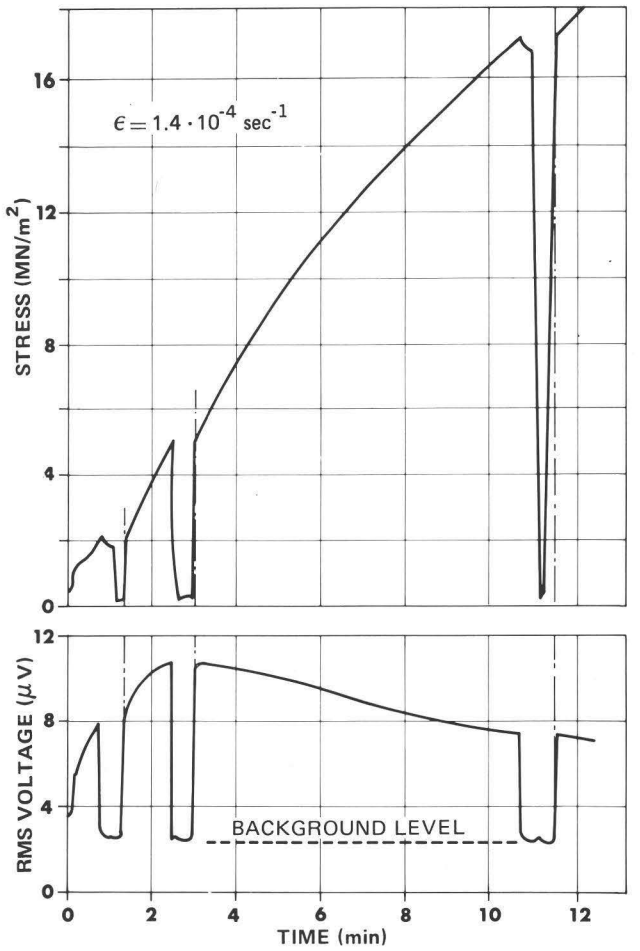


Fig. 5 : Variation of acoustic emission and flow stress with time during a tensile test. The cross-head motion was reversed three times for a short period

strong emission at the early stages of single-crystal deformation. Measurements on specimens with different grain size show once more the strong relationship between defect structure, flow-stress and acoustic emission. In Fig. 8 it can be seen that different crystals with different grain size emit the same signal, if we compare the states characterized by the same flow stress.

Of course the deformation in materials with coarse grains sets in at stresses much below the yield stresses of fine-grained specimens.

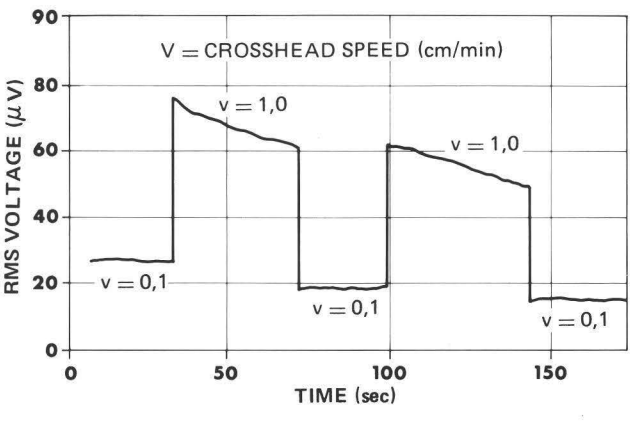


Fig. 6 : Dependence of emission on the strain rate during deformation stage III in Al single crystal

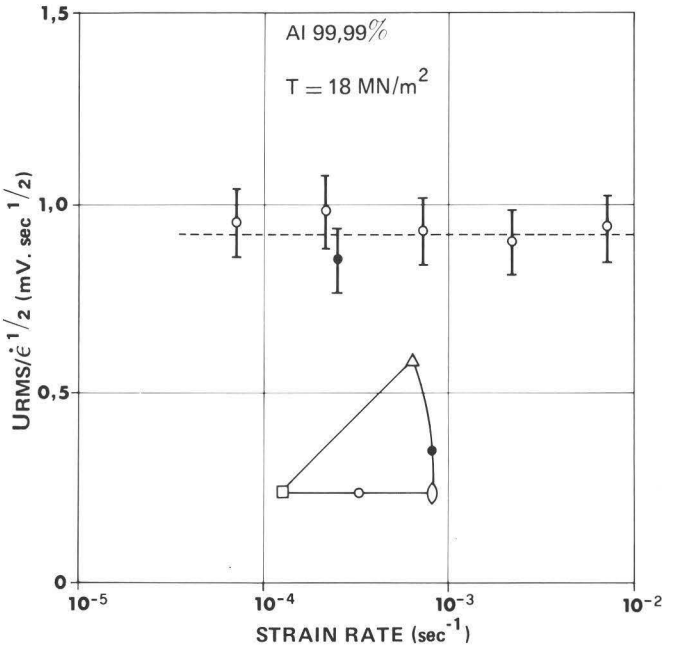


Fig. 7 : Acoustic emission vs. strain rate, at constant flow stress

Impure polycrystals (99.5% Al)

Because of the change from pure to impure crystals the signal is modified in several ways. The RMS signal becomes smaller than the signal in comparable pure specimens (Fig. 8). It has its maximum value at the yield point (Fig. 9) and the emission now contains a remarkable number of bursts. Their integrated energy is, however, still small compared to the energy contained in the continuous emission. The findings on the dependence on velocity shown for the single crystals are valid in this case too.

Aluminium-4% copper alloy at different aging stages

The alloy, manufactured in the Materials Division, was quenched from different temperature stages, namely 520°C and 590°C, and then aged at a constant temperature of 190°C for different lengths of time.

In age-hardened alloys, maximum hardening is associated with the presence of zones or intermediate precipitates, whilst overaging corresponds to growth of an intermediate phase and to the appearance of the equilibrium precipitate. In general, hardening effects will be related to the volume fraction of the dispersed phase. The quenching from 590°C, a temperature higher than the eutectic temperature of 548°C, was done in order to have large precipitates of the second phase at grain boundaries and consequently less second phase in the matrix itself. With such a material it was our intention to investigate the influence of the second phase, its structure and its dimensions, on the emission of ultrasonic signals during deformation at room temperature and to correlate acoustic stress wave emission measurements with hardness measurements.

The experiments gave a very small continuous emission and a total number of bursts much higher than in single crystals and polycrystals of aluminium. The results are plotted in Fig. 10 and were obtained in this case via the part of the electronic equipment which utilizes the demodulation stage, as shown in Fig. 1. The experiments were

performed at constant strain rate, at room temperature and using a piezoelectric transducer with a resonant frequency of 140 kc.

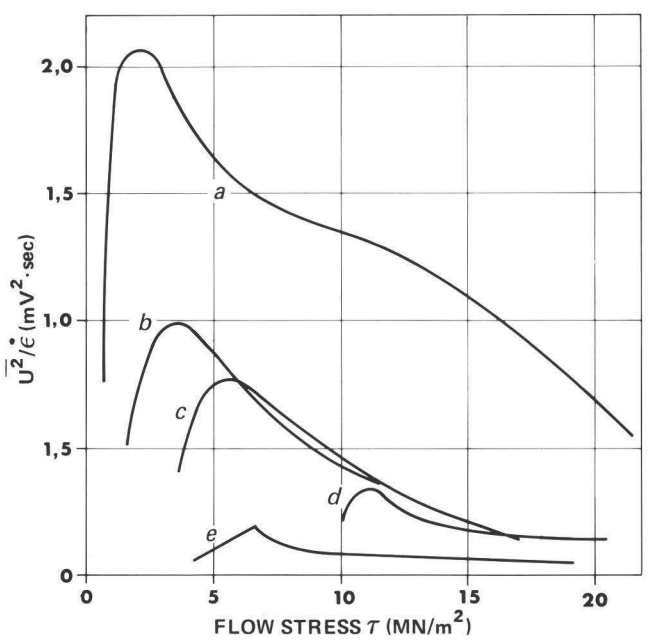
The data show a peak of emission at an aging time of 60 min (Fig. 10), in contrast with hardness measurements where maximum values are reached after one day of treatment at 190°C. In these alloys the hardening observed is attributed to localized concentrations of copper atoms forming zones. At aging temperatures higher than 100°C, the zones designated GP [2] sometimes θ'', have a structure which although only a few layers thick is considered to be three-dimensional and to have an ordered atomic arrangement. Increasing the aging time a transition phase, θ', exhibiting coherency with the solid solution lattice, forms after GP [2] but coexists with it over a range of time. The final stage in this sequence is the transformation of θ' into the noncoherent precipitate θ. Maximum hardness and strength occur when the amount of GP [2] is essentially at a maximum, although some contribution may be provided by θ'.

In Fig. 10 the difference in number of bursts emitted during deformation from the samples quenched from two temperatures is related to the number of second-phase precipitates.

Eutectic composite alloy
Al-Al_3Ni unidirectionally solidified

Measurements were performed on samples, manufactured in the Materials Division, prepared under controlled solidification conditions in order to obtain a cellular morphology.

Two types of dependence of the acoustic emission on deformation were observed (Fig. 11). The first type of specimen shows a dependence of the emitted energy on the deformation very similar to that of aluminium, with a rapid increase at the very beginning of the deformation and a maximum at the onset of plastic flow. The second type of specimen is characterized by a much lower value of energy emitted, which reaches a plateau before rupture.



(a) Al 99.99% single crystal
(b) Al 99.99% polycrystal, grain size 2 mm
(c) Al 99.99% polycrystal, grain size 0.2 mm
(d) Al 99.99% polycrystal, without annealing
(e) Al 99.5 % polycrystal, grain size 0.05 mm

Fig. 8 : Dependence of acoustic emission on flow stress in different Al specimens

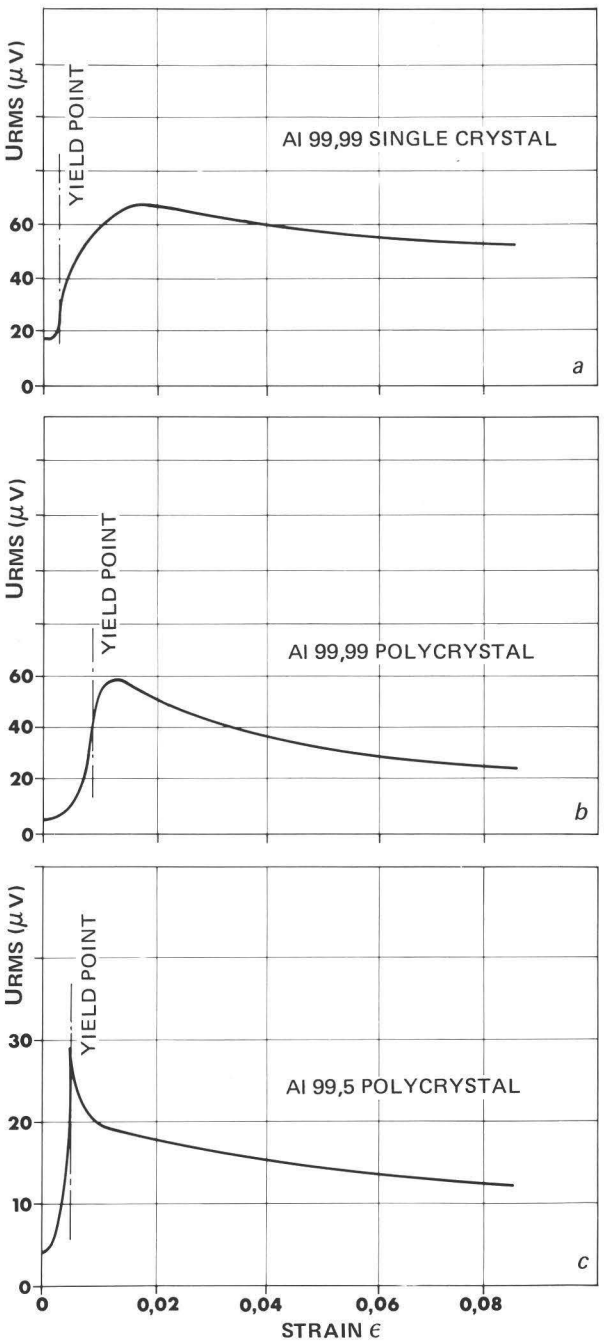


Fig. 9 : Acoustic emission of different Al specimens at constant strain rate

The difference in acoustic emission between the two types of specimen is parallel to the difference in the elasto-plastic behaviour, the first type of sample having a much greater plastic zone than the second one.

These observations can be related to the quantitative differences in morphological parameters (cell sizes, percentage of cellularity, interfibre spacing).

Discussion

The results described above can be explained qualita-

tively in the following way:

• There is no doubt that in pure aluminium single crystals acoustic emission occurs only during plastic deformation (Fig. 5).This means that acoustic emission is caused by moving dislocations. The dependence of the acoustic emission on the state of deformation clearly denotes the fact, that the dislocation structure of the material is an important parameter for the intensity of the emission.

Higher deformation velocities mean more dislocations moving and therefore higher emission (Figs. 6 and 7). However, the emission is not due to dislocations moving with constant velocity, otherwise the observed maximum of the emission would appear at the beginning of the deformation in stage I, where the dislocations move over the longest path with constant velocity, and not at the end of stage II as observed (Fig. 4). Following a theory of Eshelby developed in 1962 [1] we may attribute the emission to those dislocations which are moving with changing velocity. Owing to the increasing dislocation density the number of such dislocations increases during deformation. The Eshelby theory gives also a square dependence of the emitted energy on the length of the moving dislocation segments. This is the reason why at high strains the emission decreases, since then the deformation results from a great number of short dislocation pieces.

Curves of the type shown in Figs. 9a and 9b can therefore be explained by the fact that at the beginning of the deformation the emission increases because of the increase of dislocations, which move in a non-uniform way, and later decreases because of the shortening of the moving dislocation segments.

• In polycrystals no new emission was observed. This means that, at any rate in aluminium at room temperature, the grain boundaries do not contribute to acoustic amission. In polycrystals the length of dislocations is limited by the grain size, hence the emission is smaller than in single crystals. The same reasoning accounts for the still smaller emission in impure materials (Figs. 8 and 9).

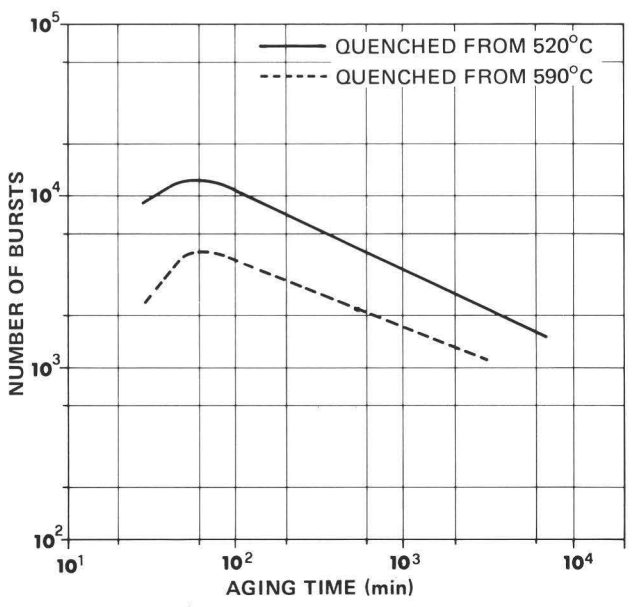


Fig. 10 : Total number of bursts in Al-4 % Cu after different heat treatments and aging times

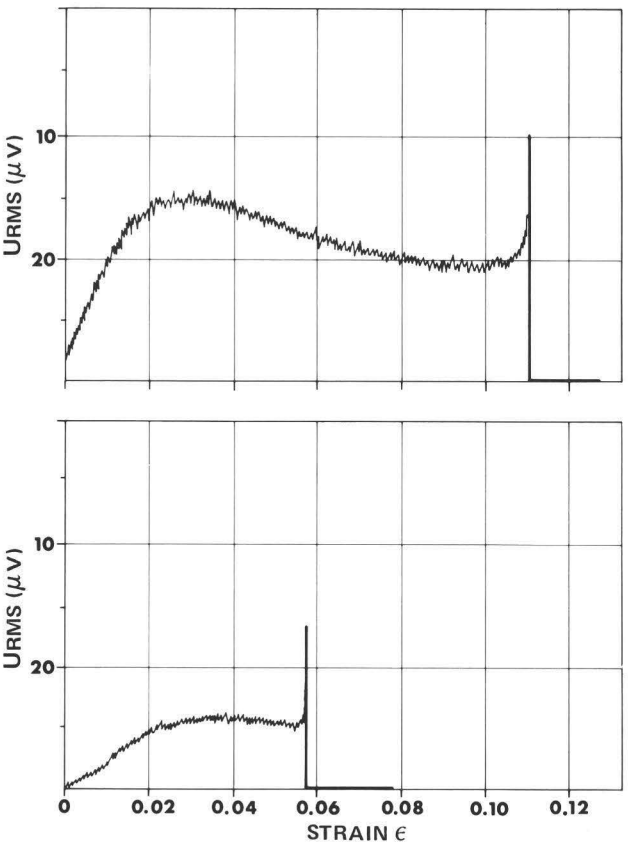


Fig. 11 : Acoustic emission in unidirectionally solidified Al-Al_3Ni alloy with different morphological parameters

• In the aluminium-copper alloys and in the fibre-reinforced materials the emission is mainly composed of bursts. The total number of bursts decreases with decreasing ductility, i.e. in these materials the acoustic emission is also related to plastic deformation.

In the Al-Cu alloys both the hardness or strength and the number of counts depend on the aging time. Both values exhibit a maximum. But the maximum of the counts of acoustic bursts appears after a much shorter aging time than the maximum of the strength. The strength is highest when the greatest number of precipitates, GP[2], is present in the matrix. Therefore one possible conclusion is, that the particles are not the source of bursts, but the bursts are generated by trains of dislocations which move together and give rise to signals which are much greater than the signals generated by single dislocations. In the tensile experiments we observed in this material a rather strong Portevin-Le Chatelier effect, which can be attributed to trains of moving dislocations and may tend to support our explanation.

The difference of the total emission in the two classes of fibre-reinforced materials shown in Fig. 11 can be attributed to a difference in cell size which allows the first materials to have large pieces of aluminium matrix, which can undergo plastic deformation by moving dislocations.

Under the conditions of our experiments it appears that the only sources of acoustic emission in aluminium and its alloys are moving dislocations.

References

1) J.D. ESHELBY, *Proc. Roy. Soc.*, **266**, 222-246 (1962).

The Tensile Properties of a New Superplastic Aluminium Alloy: Al-Al_4Ca Eutectic

D. Boerman, R. Matera, G. Pellegrini, G. Piatti

Several metals and alloys exhibit superplastic behaviour. A survey on these materials is given in various extensive reviews[1-4]. It can be observed that in the case of Al-base alloys, only those containing intermetallic Al_2Cu reveal superplastic effects, which are characterized by abnormal elongations and high strain-rate sensitivity (temperature $\geqslant$ 400°C) [5-8]. Other systems such as Al-Si [9] and Al-Si-Cu [10] show high strain-rate sensitivity but limited elongation. The Al-Zn superplastic alloys are considered as Zn-base alloys.

In recent research concerning the potential use of Ca metal [11] it appeared that superplasticity is attainable also in Al-Ca alloys containing a high percentage of the Al_4Ca second phase. Subsequent detailed investigations on a wide range of compositions and using different preparation methods led to the development of a new superplastic aluminium alloy, the Al-Al_4Ca eutectic [12]. In this note some preliminary results concerning the tensile properties of this alloy are reported. The Al-Ca eutectic (7.6 wt% Ca) presented here was prepared by induction melting in a graphite crucible under a positive pressure of argon, starting from slightly impure elements, respectively 99.9 Al and 99.0 Ca. The as-cast ingots were first extruded into 55x5 mm plates and then unidirectionally solidified in a rectangular graphite crucible in order to minimize porosity and to obtain the fine regular lamellar structure (Fig. 1a) already described previously [13]. Finally the plates were hot rolled (temperature $\cong$ 300°C) into 1 mm-thick sheets with the end effect of producing an intimate mixture of the two phases Al and Al_4Ca with a very fine grain size ($\sim 5\mu m$) (Fig. 1b). The volume fraction of the Al_4Ca second phase was 31%. Tensile specimens of 8 mm gauge-length and 1x2 mm gauge section were machined from the sheets. Tensile tests were carried out at temperatures varying from 20° to 600°C on an Instron machine (model TTCML) capable of various constant cross-head speeds between 0.83 $\mu m\ s^{-1}$ and

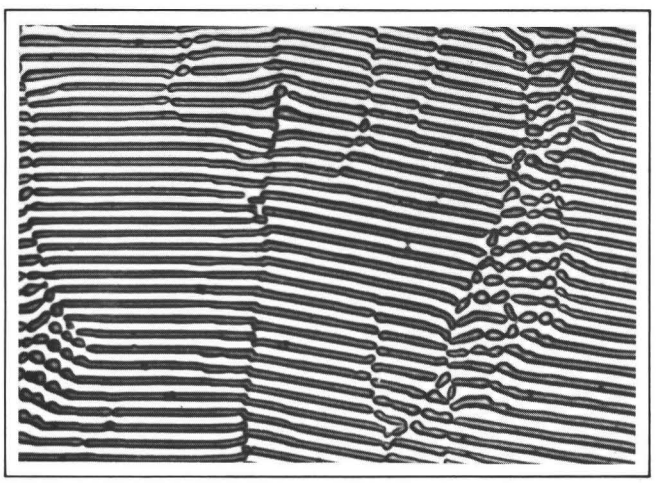


Fig. 1 : a) Microstructure of Al-7.8 wt% Ca eutectic alloy (x 500) Unidirectionally solidified (transverse section)

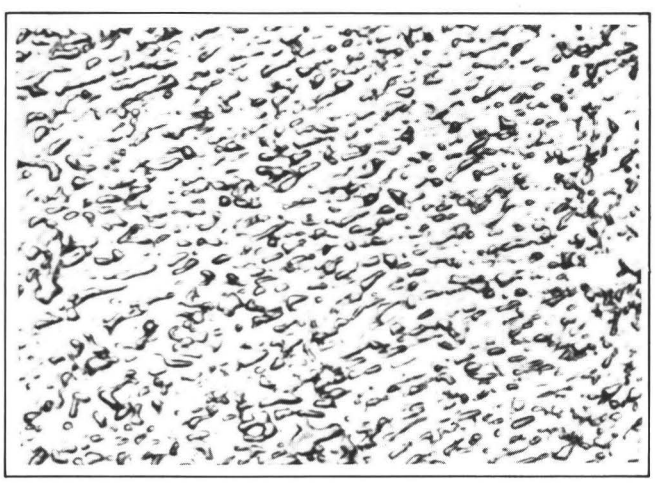


Fig. 1 : b) Microstructure of Al-7.8 wt% Ca eutectic alloy (x 500) Superplastic (after casting and heavily hot-working)

Table 1 : Superplastic tensile properties of the Al-Al_4Ca eutectic

Temperature °C	Cross-head speed ($\mu m\ s^{-1}$)	Total plastic elongation (%) (maximum values)	Maximum engineering stress ($MN\ m^{-2}$) (mean values)	Strain-rate sensitivity index (m) (maximum values)
300	33.3	220	39.2	–
400	33.3	351	14.7	–
450	1.6-3.3-8.3-16.7-33.3-83.3-166.6	385	8.8	0.4
500	1.6-3.3-8.3-16.7-33.3-83.3-166.6	532	4.4	0.72
550	1.6-3.3-8.3-16.7-33.3-83.3-166.6	850	2.9	0.78
600	33.3	540	1.9	–

8.33 mm s^{-1}. An Adamel air furnace was used with a constant temperature zone (± 2°C). The strain-rate sensitivity was determined at 450, 500 and 550°C by calculating the slopes of the flow stress/true strain-rate curves following the method developed by Dunlop and Taplin [14] and used recently by Ducheyne and De Meester [15].

A summary of the superplastic tensile properties of the Al-Al_4Ca eutectic is given in Table 1. It appears clearly that the optimum temperature range for superplasticity lies between 500 and 600°C. This is actually expected for an eutectic alloy near to the melting point [4] (in our case 616°C). At lower temperatures the superplastic behaviour is still evident. A beginning is observed around 300°C = 0.64 T_m, T_m being the homologous temperature in Kelvin. This value is slightly above the minimum temperature for the occurrence of superplasticity, which is 0.5 T_m = 171.5°C [1-4]. The maximum elongation (850% at 550°C) corresponds to a strain-rate of 1.3 x 10^{-2} s^{-1}, while the maximum strain-rate sensitivity index (m = 0.78) corresponds to a strain-rate of 1.3 x 10^{-3} s^{-1}. At this moment we cannot confirm the statement that maximum elongations occur frequently under conditions of maximum m [3].

The superplastic behaviour emerges clearly also from Figs. 2 and 3. Fig. 2 represents some typical engineering stress-strain curves obtained at different temperatures (400, 450 and 500°C) with an initial strain-rate of 4.1 x 10^{-3} s^{-1}. Fig. 3a exhibits a sigmoidal relationship between log-stress and log-strain at 450, 500 and 550°C, with a region of high strain-rate sensitivity (m > 0.3) ($m = \delta \log \sigma / \delta \log \dot{\epsilon}$ [16] where σ is the flow stress and $\dot{\epsilon}$ the true strain-rate), in which superplasticity occurs. This region is bounded by two regions of low strain-rate sensitivity (m ~ 0.1), both corresponding to conventional plasticity. This trend is typical of many other superplastic systems [3], e.g. the eutectic Al-Al_2Cu [5-6]. Fig. 3b shows the dependence of the strain-rate sensitivity m on the true strain-rate at different temperatures. As for other systems [3], the strain-rate sensitivity increases with increasing temperature and goes through a maximum with increasing strain-rate. A point worth noting is that the peak of m occurs at decreasing strain-rate as the temperature increases. On this point Al-Al_2Cu [5] and Al-Al_4Ca behave differently.

The tensile properties of the Al-Al_4Ca eutectic at room

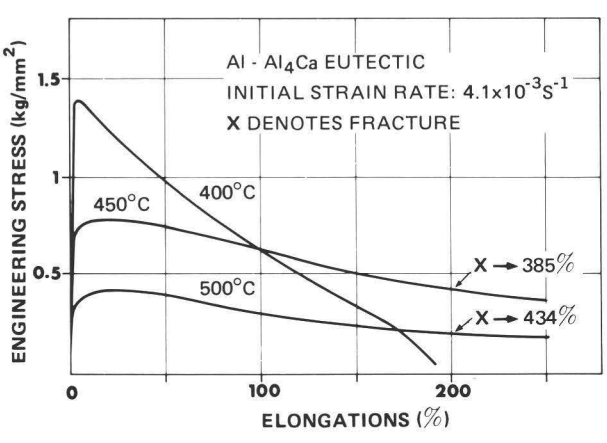


Fig. 2 : Engineering stress elongation curves for the Al-Al_4Ca eutectic (1 kg/mm^2 = 9.80665 Mn m^{-2})

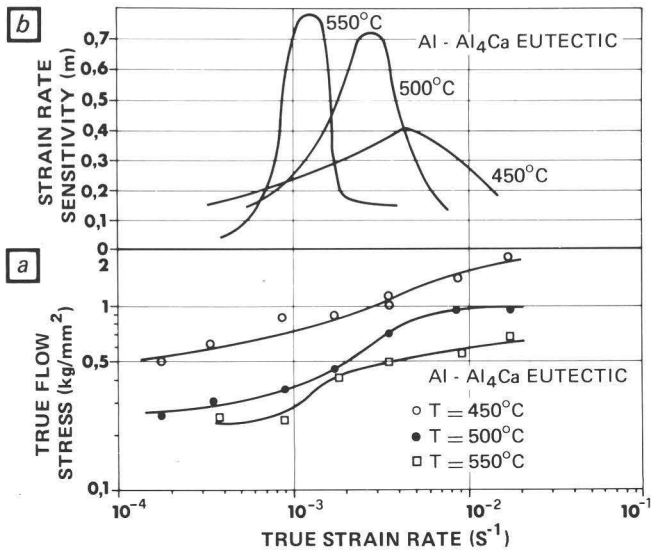


Fig. 3 : a) Relationship (Dunlop and Taplin method) between flow stress and true strain-rate for Al-Al_4Ca eutectic (1 kg/mm^2 = 9.80665 Mn m^{-2}

b) Dependence (derived from Fig.3a) of strain-rate sensitivity index, m, on true strain-rate

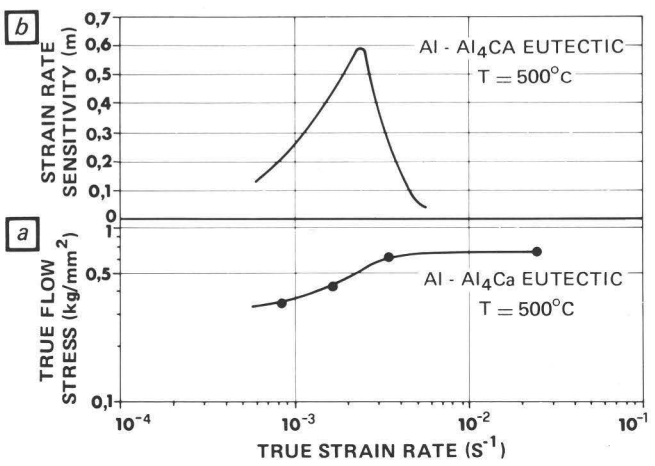


Fig. 4 : a) Relationship between flow stress and true strain-rate for Al-Al_4Ca eutectic (Jovane method) (1 kg/mm^2 = 9.80665 Mn m^{-2})

b) Dependence (derived from 4a) of strain-rate sensitivity index m, on true strain-rate

temperature are given in Table 2 together with those obtained on the material after superplastic deformation (elongation 15%) at 400°. For reasons of comparison the tensile properties of an Al-Al_4Ca unidirectionally solidified eutectic already described elsewhere [17] are also reported in the Table (column 4). Lastly, Table 2 contains some data regarding the hardness and the density of the specimens used in the present investigations.

The eutectic Al-Al_4Ca was also prepared by use of a second method based on a random solidification technique (chill cast into a graphite crucible) and subsequent hot working (extrusion and hot rolling). It is interesting to note that the specimens prepared in this way revealed a very fine equiaxial-grain duplex structure with superplastic behaviour. In this case however, the superplasticity was tested on sheets at 500°C following the method developed by Jovane [18-19]: a primary vacuum (10^{-1} mm Hg) is

Table 2 : Room temperature characteristics of the Al–Al_4Ca eutectic

Properties	Superplastic structures	Structures after superplastic deformation at 400 °C	Cast structures (unidirectionally solidified)(ref.17)
Ultimate tensile strength (MN m^{-2})	245 – 323	196 – 235	225 – 255
Total plastic elongation (%)	3 – 6	7 – 11	7 – 35
Hardness (kg/mm^2)	60 – 90 (H_V)	74 (H_V)	38 – 52 (H_B)
Density (g/cm^3)	2.59	–	–

applied to one side of a test disc to form a dome, the increase in height of the dome being measured by a transducer and the depression by a vacuum gauge. The stress/strain rate curves (Fig. 4a) were obtained from the theoretical approach of the deformation of a dome in superplastics materials [18-19]. Fig. 4b shows the dependence of strain-rate sensitivity index, m, on strain-rate. In Fig. 5 we show finally a) a dome obtained from a test disc of 0.3 mm thickness at 500°C; b) a cup of 0.07 mm thickness made from an analogous disc by deep-vacuum forming at the same temperature.

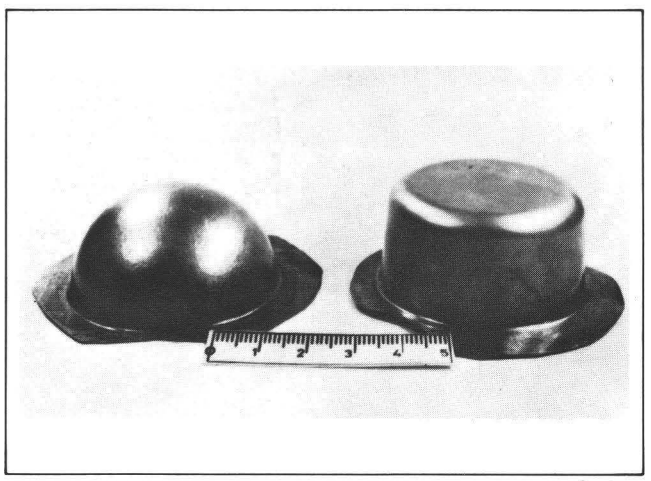


Fig. 5 : A dome vacuum formed (a) and a cup vacuum formed (b) into a die, both from superplastic Al-Al_4Ca eutectic at 500°C

References

1) F. JOVANE, *La Metallurgia Italiana,* **59,** 293 (1967)

2) R.H. JOHNSON, *Met. Rev.,* **15,** 115 (1970)

3) G.J. DAVIES, J.W. EDINGTON, C.P. KUTLER and K.A. PADMANABBAN, *J. Mat. Sci.* **5,** 1091 (1970)

4) B. BAUDELET, *Mémoires Scientifiques Rev. Métallurg.,* **68,** 479 (1971)

5) D.L. HOLT and W.A. BACKOFEN, *Trans. A.S.M.,* **59,** 755 (1966)

6) M.J. STOWELL, J.L. ROBERTSON and B.M. WATTS, *Met. Sci. J.,* **3,** 41 (1969)

7) G. BEGHI, R. MATERA, G. PIATTI, *J. Mater. Sci.,* **5,** 820 (1970)

8) B.M. WATTS, M.J. STOWELL, *J. Mater. Sci.,* **6** 228 (1971)

9) E.E. UNDERWOOD, *Trans. AIME,* **229,** 914 (1962) and *J. Metal,* **54,** 914 (1962)

10) D.L. HOLT, *Trans. A.S.M.,* **60,** 564 (1967)

11) G. PELLEGRINI and G. PIATTI, *Eurospectra* **13,** 112 (1974)

12) EURATOM – J.N.R.C. ISPRA (Patent Pending)

13) K.N. STREET, C.F. St. JOHN, G. PIATTI, *J. Inst. Met.* **95,** 326 (1967)

14) G.L. DUNLOP, D.M.R. TAPLIN, *J. Mater. Sci.,* **7,** 84 (1972)

15) P. DUCHEYNE and P. DE MEESTER, *J. Mater. Sci.,* **9,** 109 (1974)

16) W.A. BACKOFEN, I.R. TURNER, D.H. AVERY, *Trans. A.S.M.,* **57,** 980 (1964)

17) R. MATERA, G. PIATTI, K.N. STREET, *Aluminium* **49,** 335 (1973)

18) F. JOVANE, *Met. Ital.,* **59,** 923 (1967)

19) F. JOVANE, V. NASO, *Met. Ital.,* **59,** 957 (1967)

Metallobiochemistry of Heavy Metal Pollution

E. Sabbioni, E. Marafante, F. Girardi

Introduction

Development of nuclear and radiochemical techniques in environmental biochemical research at the JRC Ispra was described in the Annual Report 1972 [1]. The study was continued during 1973. During 1974 the technique was essentially dedicated to *in vivo* experiments on the metallobiochemistry of heavy metal pollution, in the context of the Environmental Protection Programme. The aim is to elucidate the biological effects on mammals of daily exposure to environmental heavy metals (basically long-term low-level exposure, LLE).

In particular, the objectives of the research were (a) to study the distribution of labelled metal pollutants in organs, subcellular fractions, with a view to identifying specific cellular metal-binding components; (b) to study the effect of heavy metals on the metal-binding component, such as influence on its biosynthesis, saturation level, antagonistic effects of other metals.

In vitro studies were also carried out on potential metal-binding components, such as metalloenzymes and nucleic acids.

To meet the foregoing objectives biochemical studies must be carried out at the concentrations normally present in polluted environment. At such low concentrations the heavy metals accumulated in the body may be elused when investigated by classical biochemical means. Therefore to solve the experimental difficulties associated with these studies we applied highly sensitive nuclear and radiochemical techniques, such as:

- labelling *in vivo* nanogram or subnanogram amounts of metals (this may be difficult even with sensitive techniques such as radioactive tracing);
- detection and quantitative determination of trace amounts of metals in microsamples of subcellular components after long and complex biochemical fractionation procedures.

The complete procedure for each metal involves:

- preparation of radiotracers
- administration of the tracer to a group of laboratory animals
- sacrifice of the animals at various time intervals and measure of radioactivity in various biochemical fractions (organs, purified subcellular fractions and their components).

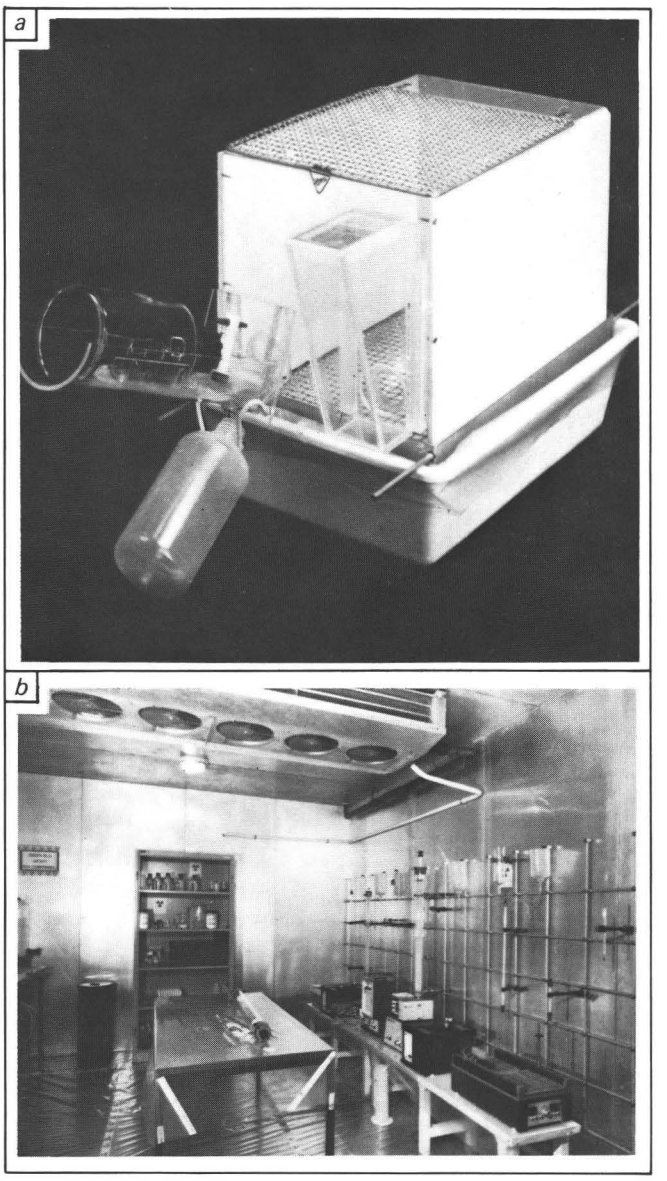


Fig. 1 : Special modular cages for "heavy metal intoxication" of rats in long term-low level exposure experiments (1a). Cold-room radiobiochemical area at +4°C to work with high level of radioactivity (1b)

Development of Special Techniques and Equipment

Biochemical studies on heavy metals at typical environmental concentrations call for rather sophisticated materials, equipment and facilities which must largely be developed "ad hoc". The most important realizations of 1974 and 1975 were:

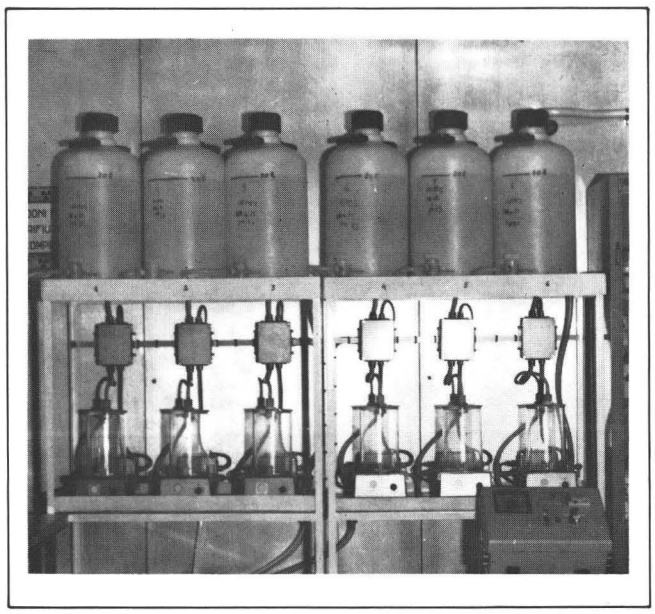


Fig. 2: Automatic dialyser developed for night-time dialysis of biochemical metal-binding components with relatively high radiation level

a) Stabularium and Cold-Room Radiochemical Facilities:
a stabularium radiochemical area which can contain 100 rats in special modular cages was developed for long-term experiments. The cages have a special water-supply device which minimizes radioactive contamination of cages and rats by the radiotracers which are administered via drinking water (Fig. 1a).
A cold-room radiochemical area at + 4°C equipped with gel chromatography apparatus and designed to work with high levels of radioactivity was set up to minimize the temperature-dependent artifacts during biochemical fractionations (Fig. 1b).

b) Development of an Automatic Dialyzer:
this apparatus was constructed for automatic extensive dialysis during night periods in order to minimize operator time and to diminish the risk arising to persons from relatively high radiation levels. The apparatus can simultaneously dialyse a number of samples (depending on size) against six different buffers (Fig. 2). It is used routinely in the systematic study of the interaction of heavy metals and macromolecules.

c) Preparation of Special Radiotracers with a Very High Specific Activity
The radioactive isotopes used for this study were prepared:
- by proton irradiation at the cyclotron of Milan University. The same laboratory measured the excitation function for each radioisotope, while isolation, purification, preparation for biological use and analytical controls were set up by our laboratory. The experimental excitation function for the production of ^{203}Pb, which was also used for other environmental studies on lead pollution, has already been reported in a previous paper [2]. Fig. 3 shows the experimental excitation function for the production of carrier-free ^{65}Zn and ^{48}V.
- by neutron activation in nuclear reactor.

Table 1 shows the tracers used and the production and detection modes.

d) Development of Radio-biochemical Techniques for the Fractionation and Purification of Subcellular Fractions:
the estimate of the biochemical purity of the subcellular fractions from organ homogenates and of molecular metal binding components from fractioned subcellular fractions requires great caution. We have adopted *in vivo* incorporation of radioactively labelled precursors into biochemical fractions as "markers" of subcellular compoents, such as ^{14}C-arginine as marker for histone and ^{3}H-triptophan for non-histone nuclear proteins, ^{35}S-cysteine as marker for cadmium-binding protein (see *in vivo* experiments, cadmium) and ^{3}H-orotic acid as marker for ribonucleic acid.

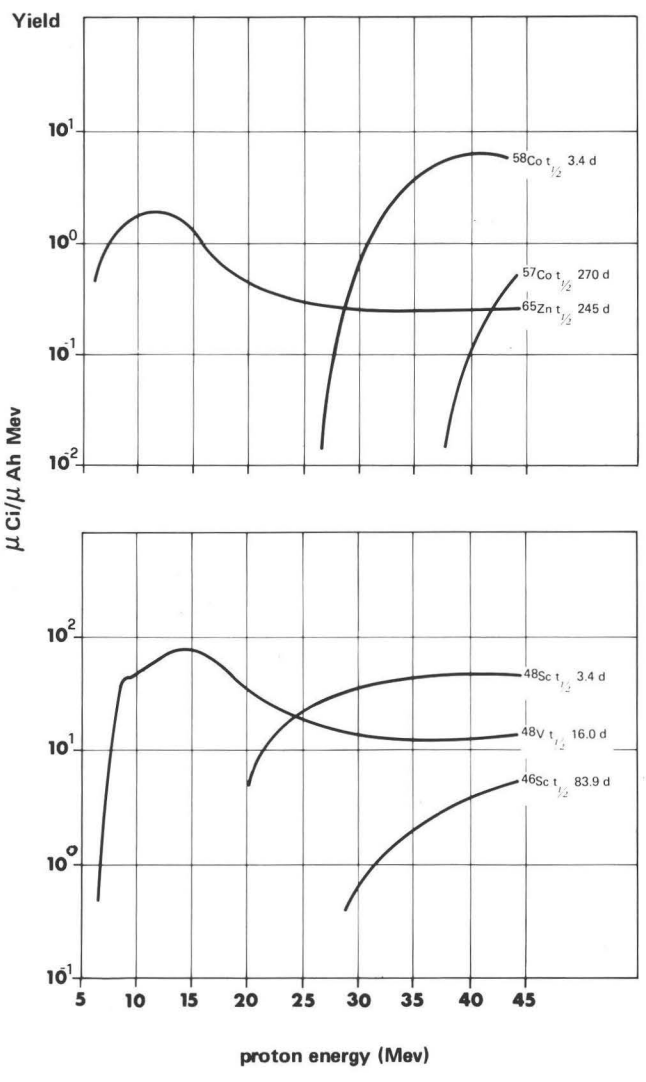


Fig. 3: Excitation functions for the production of ^{65}Zn and ^{48}V carrier-free in a natural copper and titanium target

Table 1 : Radiotracers involved in the metallobiochemistry of heavy metal pollution. Preparations were performed at the cyclotron of the Milan University or at Triga Mark II of Pavia University reactor. The other tracers were supplied by Radiochemical Centre, Amersham (England)

Radiotracer	T 1/2	Principal emission (MeV)	Source	Specific activity (mCi/mg)	Counting method adopted
^{106}Ag	8.3 d	0.51 1.05	Cyclotron	c.free	γ-ray spectrometry
^{74}As	26.5 h	0.66	Nuclear reactor	10	Cerenkov counting
^{198}Au	2.8 d	0.41	Nuclear reactor	100	Cerenkov counting
^{7}Be	53.6 d	0.48	Cyclotron	c.free	γ-counting
^{206}Bi	6.4.d	0.18 0.34	Cyclotron	c.free	γ-ray spectrometry
^{109}Cd	450 d	0.022 Ag X-ray 0.088 via ^{109m}Ag	Rad.Centre - Cyclotron	c.free	γ-counting
^{60}Co	5.3 y	1.17 1.33	Nuclear reactor	20	Cerenkov counting
^{51}Cr	27.8 d	0.32	Cyclotron	c.free	γ-counting
^{64}Cu	12.1 h	0.51 1.34	Nuclear reactor Cyclotron	10	γ-ray spectrometry
^{203}Hg	45.8 d	0.28	Nuclear reactor	2	γ-counting
^{192}Ir	74 d	0.31 0.46	Nuclear reactor	15	Cerenkov counting
^{54}Mn	314 d	0.84	Rad.Centre	c.free	γ-counting
^{99}Mo	2.8 d	0.74 0.14	Nuclear reactor	1	Cerenkov counting
^{63}Ni	80 y.	0.067	Rad. Centre	5	Liquid scintillation counting
^{203}Pb	2.2 d	0.28 0.40	Cyclotron	c.free	γ-ray spectrometry
^{75}Se	127 d	0.14 0.27	Nuclear reactor	10	γ-counting
^{113}Sn	119 d	0.39 via ^{113m}In	Rad. Centre	15	γ-counting
^{125m}Te	58 d	0:11 0.035	Rad. Centre	c:free	γ-ray spectrometry
^{201}Tl	3 d	0.03 0.135	Cyclotron	c.free	γ-ray spectrometry
^{48}V	16.2 d	0.99 1.31	Cyclotron	c.free	γ-counting
^{65}Zn	245 d	0.51 1.115	Cyclotron	c.free	Cerenkov counting

In the squares: elements recognized as of prime importance in the declaration on the Environment Action Programme of 22.11.1973 by the Council of Ministers (29) and selected as a first priority in our study

In Vivo Experiments

Cadmium

Cadmium progressively accumulates with age in liver and kidney tissues [3]. It has been demonstrated that administration of Cd^{2+} stimulates the biosynthesis of a cytoplasmatic cadmium-binding protein (Cd-BP) which could act as a detoxifying agent for cadmium [4]. The following studies have been carried out:

a) interaction of heavy metals with rat liver CdBP: the study was performed by using a combination of neutron activation analysis, radiochemical methods and gel chromatography. The gamma-ray spectrum of neutron-activated microsamples of CdBP demonstrates the presence of Cd, Zn, Cu, Hg and Ag at significant levels.

This was confirmed by *in vivo* radiotracer experiments, in which 21 labelled metal ions were administered to Cd-treated and control rats: only ^{109}Cd, ^{65}Zn, ^{64}Cu, ^{203}Hg, ^{106}Ag and ^{113}Sn were found incorporated into CdBP (Fig. 4), as confirmed also by electrophoretic experiments [5]

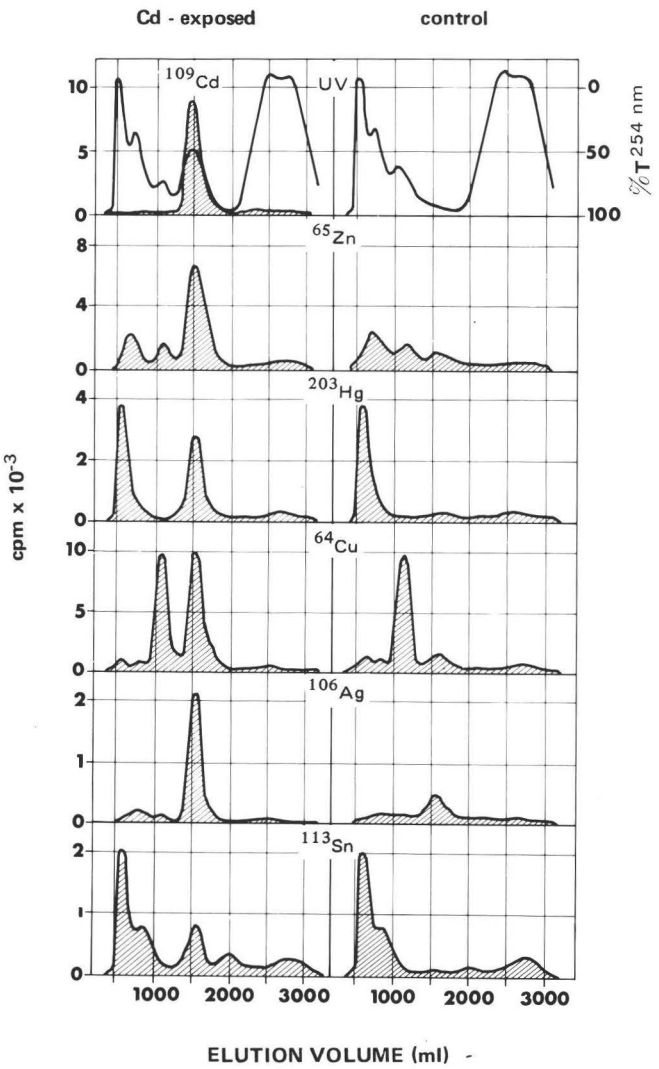


Fig. 4 : Distribution of Cd, Zn, Hg, Cu, Ag and Sn in Cd-intoxicated and control rat liver soluble fraction after Sephadex G-75 chromatography

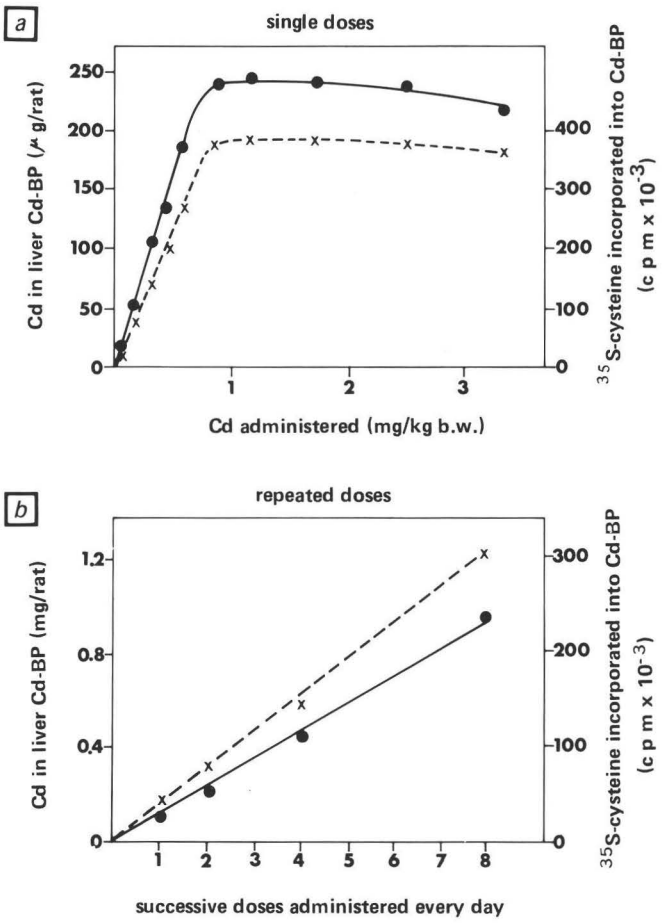


Fig. 5 : The incorporation of cadmium into rat liver CdBP and its "de novo" biosynthesis as a consequence of single (5a) and repeated (5b) cadmium intoxication.
Cadmium (-●-●-). ^{35}S-cysteine (-X--X-)

b) Studies on the biosynthesis of CdBP: rat liver CdBP contains an unusually high number cysteine residues (21 g atom per protein molecule) [6]. Incorporation of ^{35}S-labelled cysteine together with ^{109}Cd served as a marker of the "de novo" biosynthesis of CdBP. The results can be summarized as follows:

- both the incorporation of cadmium and the biosynthesis of CdBP are unaffected by the presence of 42 different metal ions;
- the Cd content of the "de novo" biosynthesized CdBP following injections of single doses of cadmium increases as a function of the applied dose and reaches a maximum concentration of about 240 μg of cadmium/rat liver after a single i.p. dose of 3 mg Cd/kg b.w. It remains unchanged for more massive cadmium administration (Fig. 5a);
- repeated doses applied at 24-hour intervals for at least 8 days give a similar dose-proportional increase in both CdBP biosynthesis and Cd incorporation, thus resulting in an additive accumulation (Fig. 5b) [7];
- long-term low-level exposure experiments (LLE): ^{190}Cd - labelled Cd^{2+} is administered daily via well-characterized mineral water in a concentration of 50 ppb. The diet of the animals was also

characterized as to its heavy metal content by neutron activation analysis (cadmium content 0.01 ppm). The lay-out of the experimental programme, which will continue during 1976, was reported in a previous paper [8]. After 6 months from the start of the experiment liver, kidney, gastrointestinal tract and pancreas are the organs in which cadmium accumulate.

Cadmium in these organs was always bound to proteins with a molecular weight of 10.000 – 11.000 (as shown by gel filtration of the soluble fractions from the homogenates). The LLE experiment on cadmium will be continued for two years.

c) Rat intestine CdBP: the toxic effects of cadmium on the gastrointestinal tract are well known [9] as well as the presence of CdBP in the duodenum [10]. No data have been reported on the induction of CdBP in the intestine of mammals. We have investigated this important question. $^{109}CdCl_2$ was given orally to rats. The animals were at the same time injected with ^{35}S-cysteine and the CdBP was isolated by gel filtration from the intestinal mucosa. Results show that in gel chromatography a cadmium peak appeared associated with a ^{35}S-cysteine peak in the position of CdBP. The inductive effect of cadmium in the intestine was fully confirmed.

This important conclusion could account for the poor absorption of dietary cadmium from the gastrointestinal tract in mammals.

Lead

The distribution of lead in organs of man is still being debated [11]. In addition, very few works are reported on its subcellular distribution [12, 13]. Our study on lead has been essentially carried out by using ^{203}Pb radioisotope to identify the lead-binding components in the hepatic subcellular fractions, and with a view to eventual long-term experiments [14].

Male rats were injected intravenously with 18µg of $^{203}Pb^{2+}$/rat as well as with radioactively labelled precursors such as ^{14}C-arginine and ^{3}H-tryptophan. The ^{203}Pb radioactivity was measured in the tissues as well as in nuclei, mitochondria, lysosomes, microsomes and soluble fractions from liver and kidney homogenates (Table 2). The subcellular fractions from the liver were purified and fractionated into macromolecular components by ultracentrifugation, gel filtration, ion exchange chromatography and solvent extraction. Nuclei were subfractionated into membranes, chromatin proteins (histone and residual non-histone proteins) and DNA. About 70% of the lead was detected in the nuclear membrane fraction exclusively bound to membrane proteins, and absent in phospholipids (Fig. 6). Most of the intranuclear lead was found to be associated with histone fractions isolated from ion exchange chromatography and representing histones, other basic or very weakly acid proteins as indicated by the incorporation of [^{14}C] arginine and [^{3}H] tryptophan (Fig. 7). Lead was

Table 2 : Distribution of lead, selenium and vanadium in tissues and subcellular fractions from liver of rats intoxicated with 18 µg of Pb as nitrate, 22 µg of Se as sodium selenite and 10 µg of V as vanadyl chloride

Organs	Distribution in tissue (% of the dose administered)		
	Lead	Selenium	Vanadium
Liver	4.06	5.6	1.5
Kidney	8.6	1.7	1.17
Testicles	0.03	0.3	0.0006
Spleen	0.075	0.1	0.0005
Lung	0.11	0.2	0.0004
Heart	0.016	0.08	0.0002
Brain	0.0067	0.03	0.00004
Subcellular fraction from liver	**Intracellular distribution (% of total homogenate)**		
	Lead	Selenium	Vanadium
Nuclei	28.3	50.8	44.3
Mitochondria	9.5	7.2	11.3
Lysosomes	10.8	10.4	14.2
Microsomes	10.9	21	4
Soluble fraction	39.2	10.1	26.1

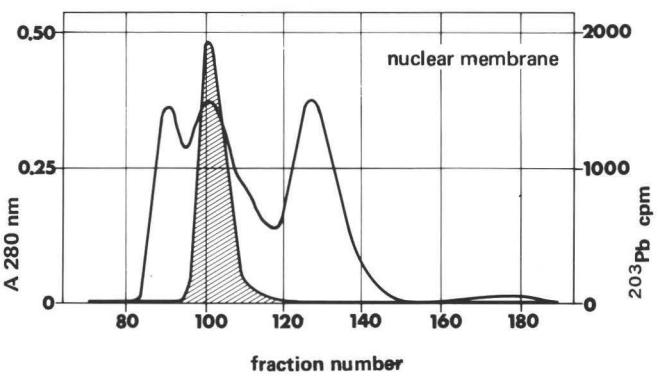


Fig. 6 : UV and ^{203}Pb elution profiles, from Sephadex G-150, of the non-delipidated nuclear membranes from rat liver

significantly contained in the chromatographically purified DNA fraction, but whether the lead was really bound to nucleic acid is not clear from this study. Fig. 8 summarizes the results and the procedures used for the identification of rat liver nuclear lead-binding components.

Mitochondria were fractionated into heavy, soluble and light subfractions representing the inner membranes, the intramitochondrial matrix and the outer membranes respectively. All these subfractions contained appreciable amounts of lead, in the order inner membranes > soluble > outer membranes. No appreciable amount of lead was present in lipids of the mitochondrial membranes.

A significant amount of lead was found associated with endoplastimatic reticulum. Fractionation of microsomes into rough and smooth membranes showed that most of the lead was bound to membranes of rough-surfaced microsomes associated with the heavy rough membranes subfraction.

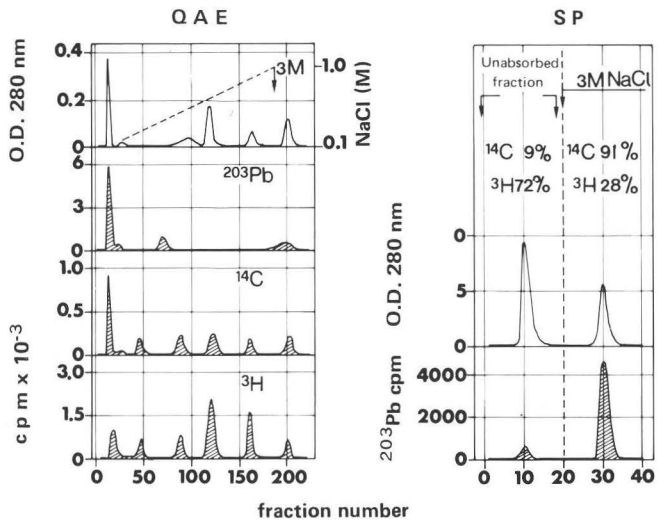


Fig. 7 : Ion exchange chromatography of the ^{203}Pb, ^{14}C-arginine and ^{3}H-tryptophan bulk chromatin from rat liver. QAE: anion exchange chromatography. The unadsorbed proteins (histone fraction) were collected after washing with equilibrqting buffer and the adsorbed components were eluted by a linear gradient of NaCl (dotted line). The arrow indicates the elution stepwise with 3M NaCl. SP: cation exchange chromatography (see QAE). The unbounded components (non-histone fraction) were eluted only with 3M NaCl

No significant lead was present in the free polysomes microsomal subfraction or in lipids of the endoplasmatic reticulum.

More than one lead-binding site was identified in the soluble fraction, the high molecular weight components representing the most important lead-binding site.

Dialysis experiments showed that lead was removed from the nuclear, mitochondrial and microsomal membranes with more difficulty than from soluble cellular components such as bulk chromatin, soluble mitochondrial subfraction and soluble cytoplasmatic fraction.

Selenium

It has been observed that the relatively high levels of selenium in the tissues, and essentially the brain, of seats may very well represent a hazardous body burden [15]. Recently it has also been shown that one form of muscular degeneration is a selenium-responsive myopathy [16]. Table 2 shows the distribution of ^{75}Se-labelled selenite, after a single i.p. injection in organs, subcellular fractions and various nuclear components of the hepatic cell. As can be seen:

- the highest concentrations of selenium in rats were found in liver, kidney, followed by testicles, spleen and lung.
- Most of ^{75}Se radioactivity is present in the nuclear fraction. About 50% of ^{75}Se radioactivity was associated with membranes, while 50% was present in the chromatin. The radioselenium associated with membranes was not bound to lipids after subfractionation and gel chromatography of the membranes.

  Dialysis experiments showed that ^{75}Se is strongly bound to the nuclear subfractions in which it has been recovered.

Vanadium

Whilst it has been suggested that the toxic effects of vanadium in the rat are related to the accumulation of the metal in the liver and kidneys [17], the intracellular distribution of vanadium in these organs is not adequately studied. Table 2 gives the findings on the distribution of vanadium (IV) in rat tissues as well in the subcellular

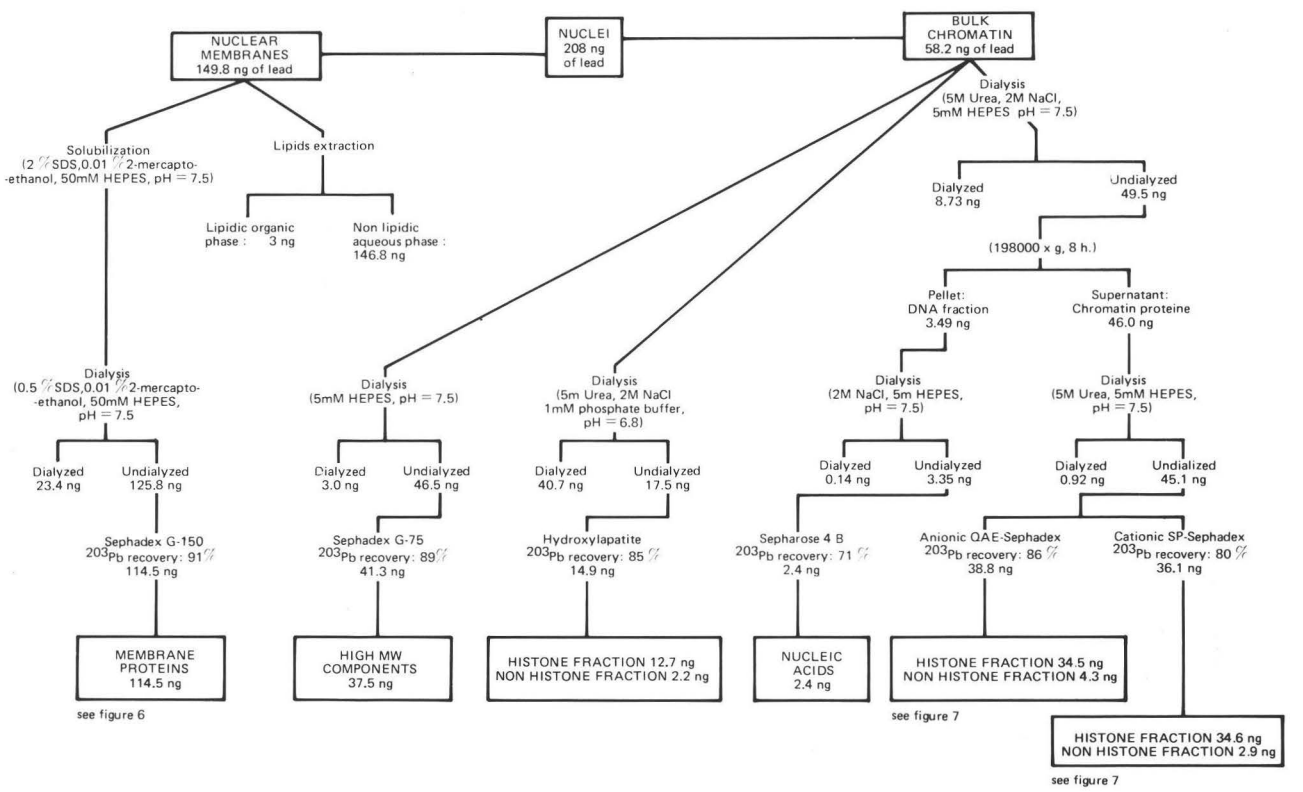


Fig. 8 : Flow-diagram and results of the experiments on identification of the nuclear binding components from rat liver

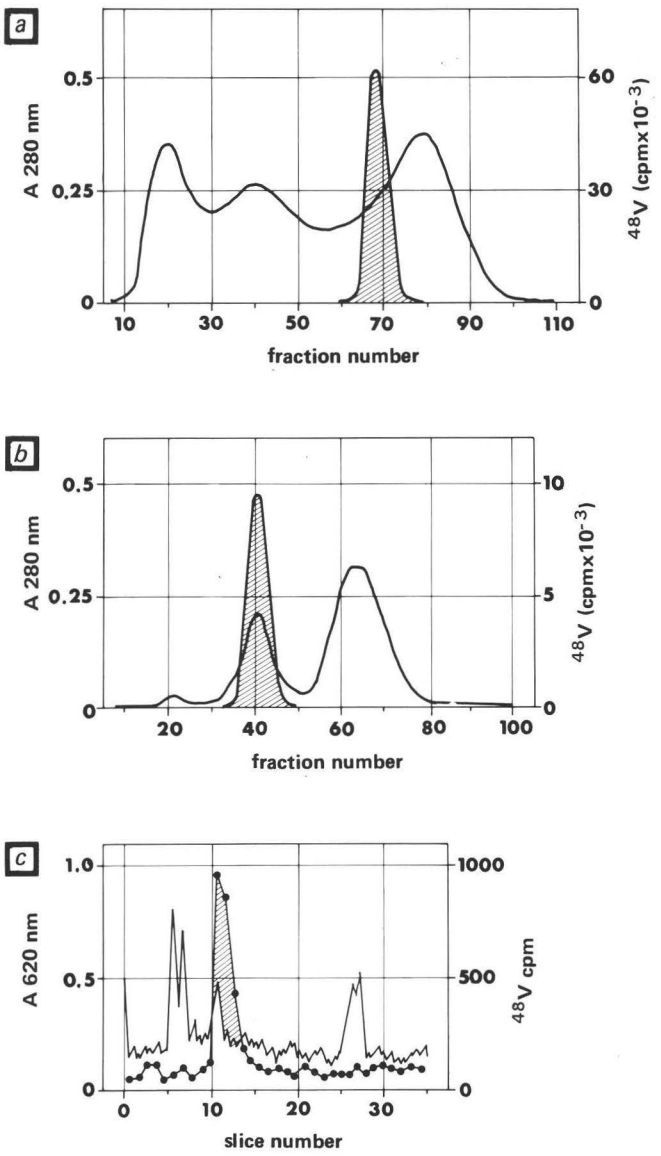


Fig. 9 : a) column chromatographic fractionation on Sephadex G-150 of serum proteins obtained from rats intoxicated with ^{48}V-labelled V (IV)

b) ion exchange chromatography on DEAE column of pooled ^{48}V peak indicated in a

c) analytical disc electrophoresis of the serum vanadium-binding component obtained by DEAE chromatography indicated in b

fractions from liver homogenate 24 hours after a single intraperitoneal injection of ^{48}V vanadyl chloride.

In the same experiments more than 90% of the ^{48}V radioactivity was present in the serum of the animals. Work was therefore undertaken to identify the serum components for intravascular transport of vanadium. The results are illustrated in Fig. 9. The following conclusions appear:

- fractionation of total serum by column chromatography on Sephadex G 150 shows that the serum vanadium is eluted as a single peak associated with serum proteins consisting of albumin and some globulins including the β_1 globulin transferrin.
- When this protein-bound vanadium was pooled and fractionated by ion exchange chromatography on DEAE-cellulose (Fig. 9b), the vanadium was found to be entirely associated with a single protein peak which is reported to be transferrin fraction [18].
- Analytical disc electrophoresis on acrylamide gel of the pooled transferrin fraction from DEAE shows that all the transferrin fraction-bound ^{48}V was consistently associated with a single protein component (Fig. 9c). The identification of this component is under investigation.

Distribution of Heavy Metals in the Subcellular Fractions of Rat Liver: Systematic Study in the Soluble Fraction

The liver and kidney are important organs of accumulation for many heavy metals [19]. For this reason, we started a study of their intracellular distribution in the rat liver soluble fraction. Fig. 10 shows the results obtained after gel filtration of the soluble fraction from liver homogenate, showing the elution profiles of proteins and radioactivities. The following conclusion can be drawn:

- Cd and Ag were present only in the region of molecular weight about 10.000 – 11.000.
- All other metals were always recovered in association with the fraction of high molecular weight components. Zn, Hg and Sn were present also in the region corresponding to a molecular weight of 10.000 – 11.000 while Tl, Cr, Be and Pb were bound to lower molecular weight.

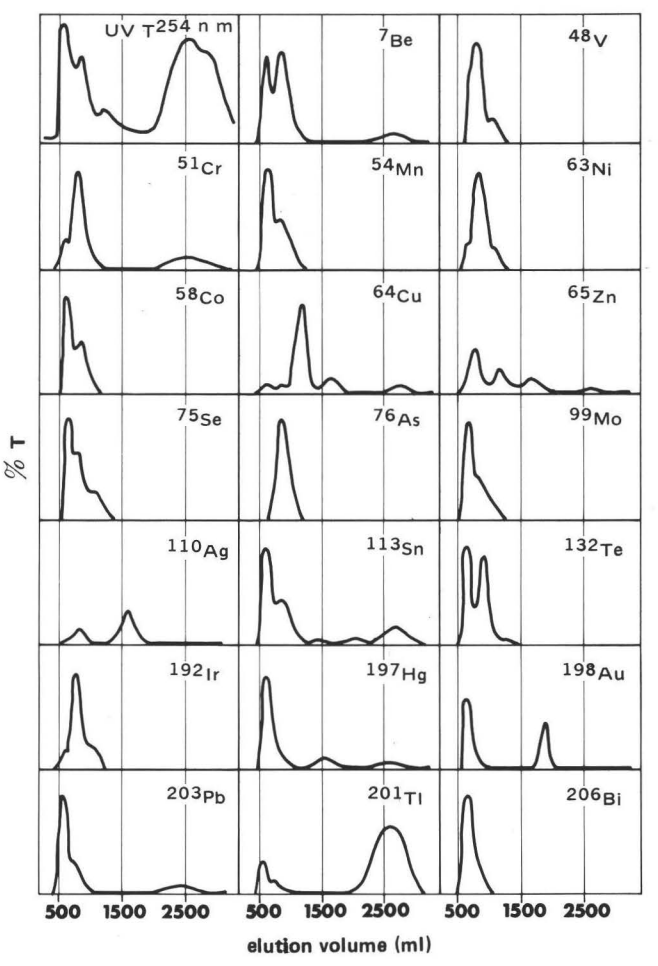


Fig. 10 : Distribution of 20 heavy metals in the soluble fraction from liver homogenate of rats intoxicated with a low dose of different metal ions

– Au was also associated with a specific component (MW = 5.000 – 6.000) and Cu with a specific protein, probably cytocuprein (MW = 30.000 – 35.000).

It appears therefore that high molecular weight components of the rat liver soluble fraction are greatly involved in the metabolism of heavy metals. The study of the biochemical nature of these components is essential for identification of the metal-binding sites.

In Vitro Studies

Interaction of Lead with Metalloenzymes: a Lead-alkaline Phosphatase

Radiotracing experiments with ^{203}Pb and neutron activation analysis show that Pb^{2+} ions can interact with calf-intestine alkaline phosphatase by different mechanisms:

- the purified native protein [20] does not bind a significant amount of additional Zn^{2+} ions, whilst it binds Pb^{2+} ions in a molar ratio Pb/protein 1:5 without a significant exchange of enzymatic activity.
- The inactive apoenzyme binds Zn^{2+} ions in a molar ratio of Zn/ protein 4:1 to give a Zn-enzyme recovering 85-90% of the original activity of the native protein.
- The inactive apoenzyme is capable of binding Pb^{2+} ions in a molar ratio of Pb/protein 2:1 to give a Pb-enzyme with a recovery of about 50% of the biochemical activity, even when genetic material such as DNA is used as substrate.
- The reconstituted Pb-enzyme can bind Zn^{2+} ions in a molar ratio Zn/enzyme 2:5.
- Pb and Zn atoms are not removed from the labelled Pb-enzyme and Zn-enzyme when the proteins are incubated with an excess of Zn^{2+} and Pb^{2+} ions respectively.
- Neutron activation analysis shows that Zn, which is necessary for the catalytic function of the native protein and for which the apoenzyme has a high affinity, is absent in the inactive apoprotein as well as in the reconstituted Pb-enzyme (Fig. 11). Cu, Fe and P were also found in stoichiometric amounts in the purified protein. The partial reaction of the mammalian apophosphatase with a metal pollutant (Pb) other than Zn and Co [21] may in part account for the observations of Kosmider, who has established a relationship between the toxic effect of lead and the diminished activity of the enzyme in experimental animals and man [22].

Inhibition of Enzymatic Hydrolysis of End-phosphate DNA by Iridium Chlorocomplexes

Iridium increases with age in cataractogenesis [23] and may act as a mutagen [24]. It is also an irreversible inhibitor of mammalian cell division *in vitro* even at concentrations as low as 10^{-5} M [25]. We have studied the inhibition of enzymatic cleavage of terminal phosphate from DNA by calf-intestine alkaline phosphatase [26]. The inhibitory effect is strongly influenced by the chemical form of the iridium (Table 3). While hexachloroiridate (IV) and hexachloroiridite (III) strongly inhibit the enzymatic activity of the enzyme, no inhibotory effects was observed when these

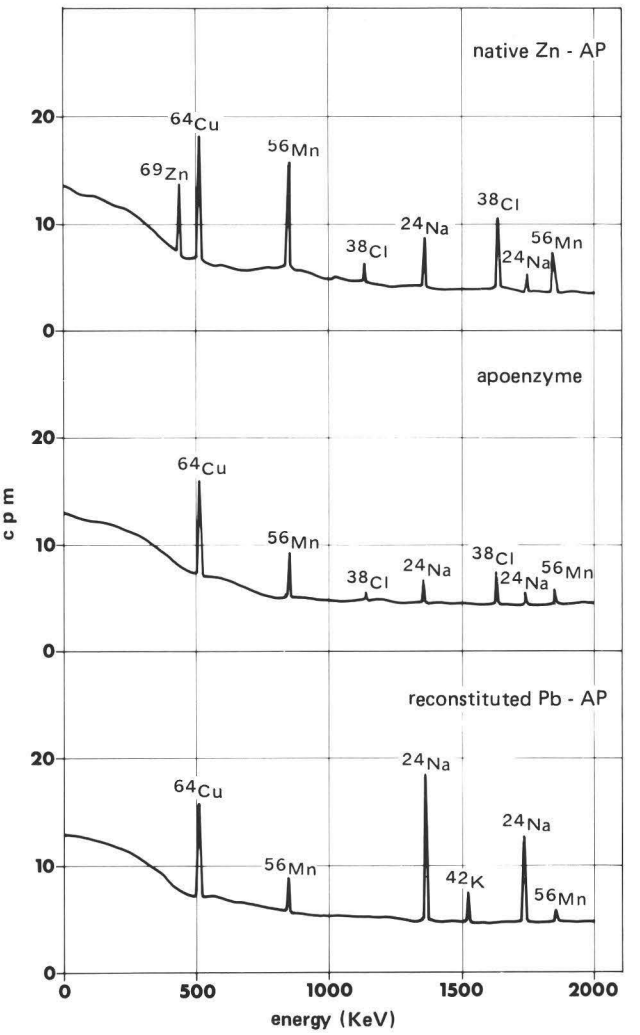


Fig. 11 : γ-ray spectra of neutron-activated microsamples of native calf-intestine alkaline phosphatase, apoenzyme and reconstituted Pb protein

chlorocomplexes were previously irradiated by light and transformed to their photochemical product.

Interaction of Heavy Metals and Nucleic Acid

Heavy metals can interact with phosphate and/or bases of nucleic acids by altering the structure and function of these bearers of genetic information. As dietary nickel was found in appreciable quantities in nuclei from rat kidney [27] we investigated *in vitro* the interaction of Ni^{2+}

Table 3 : Inhibition of calf-intestine alkaline phosphatase by iridium chlorocomplexes and its dependence on their chemical forms

Iridium chlorocomplexes	Charge of complex	Valence of iridium	Degree of inhibition %
$(NH_4)_2IrCl_6$	–2	IV	100
$(NH_4)_3IrCl_6$	–3	III	100
Photochemical product from $IrCl_6^{2-}$	0	IV	no inhibition
Photochemical product from $IrCl_6^{3-}$	0	III	no inhibition

ions with native and denaturated high polymerized calf thymus DNA previously purified on Sepharose 4B.

Preliminary results showed that the binding of Ni (II) to DNA was sensitive to changes in nickel concentration and was constant between pH = 6.5 to 7.5. At high Ni (II) concentrations binding increased rapidly, probably due to a general electrostatic attraction as observed with Mg^{2+} ions [28].

Significant differences were observed between native and denaturated DNA in binding. As thermal denaturation involves rupture of hydrogen bonds between purine and pyrimide bases, one possible explanation is to assume that Ni^{2+} ions bind the native and denaturated nucleic acid in different ways.

References

1) E. SABBIONI, F. GIRARDI, F. GIULIANI. Report EUR 5060, 358 (1972).

2) F. GIRARDI, L. GOETZ, E. SABBIONI, E. MARAFANTE, M. MERLINI, E. ACERBI, C. BIRATTARI, M. CASTIGLIONI, F. RESMINI. *Int. J. Appl. Radiat. Isotopes,* **26,** 267 (1975).

3) H.A. SCHROEDER, A.P. NASAN, I.H. TIPTON, J.J. BALASSA. *J. Chron. Dis.* **20,** 179 (1967).

4) Z.A. SHAIK, O.J. LUCIS. *Arch. Environ. Healt.* **24,** 419 (1972)

5) E. SABBIONI, E. MARAFANTE. *Environ. Physiol. and Biochem,* **5,** 132 (1975).

6) J.H.R. KAGI, B.L. VALLEE. *J. Biol. Chem.* **236,** 2435 (1961).

7) E. SABBIONI, E. MARAFANTE. *Environ. Physiol. Biochem.*, **5,** (6), 465 (1975).

8) E. SABBIONI, F. GIRARDI, E. MARAFANTE. Report EUR 5333 (1975).

9) C. SUGAWARA, N. SUGAWARA. *Jap. J. Hyg.,* **28,** 511 (1974).

10) G.W. EVANS, P.F. MAJORS, W.E. CORNATZER. *Biochem. Biophys. Res. Commun.,* **40,** 1142 (1970).

11) E. DI FERRANTE, P. BORDEAU. Report EUR 5004, (1973).

12) D. BARLTROP, A.J. BERRETTI, J.T. DINGLE. *J. Lab. Chim. Med.,* **77,** 705 (1971).

13) N. CASTELLINO, S. ALOJ. *Brit. J. Industr. Med.* **26,** 139 (1969).

14) E. SABBIONI, E. MARAFANTE, in preparation.

15) J.K. KOEMAN, W.S.M. VAN DE VEN, J.J.M. DE GOEIJ, P.S. TJIOE, J.L. VAN HAAFTEN. *Sci. Total Environ.,* **3,** 279 (1975).

16) W.G. HOEKSTRA, J.W. SULTIE, H.E. GANTHER, W. MERTZ. Trace Element Metabolism in Animals - 2. Butterworths, London (1974).

17) J.L. JOHNSON, H.J. COHEN, K.V. RAJAGOPALAN,. *Biochem. Biophys. Res. Commun.,* **56,** 940 (1974).

18) P.W. DURBIN. *Health Physics,* **29,** 495 (1974).

19) P. DURBIN. *Healt Physics,* **2,** 225 (1960).

20) M. FOSSET, D. CHAPPELET–TORDO, M. LAZDUNSKI. *Biochemistry,* **13,** 1783 (1974).

21) E. SABBIONI, F. GIRARDI, E. MARAFANTE. *Biochemistry,* **15,** (1), (1976).

22) S. KOSMIDER. *Pol. Arch. Med. Wewnet,* **32,** 1253 (1963).

23) A.A. SWANSON, A.W. TRUESDALE. *Biochem. Biophys. Res. Com.,* **45,** 1488 (1971).

24) G.M. KOLODNY. *Exptl. Cell. Res.,* **73,** 378 (1972).

25) G.R. GALE, J.A. HOWLE, A.B. SMITH. *Proc. Soc. Exp. Biol. Med.,* **135,** 690 (1970).

26) E. SABBIONI, E. MARAFANTE. *Bioinorg. Chem.,* **5,** 39 (1975).

27) P.D. WHANGER. *Toxicol. and Appl. Pharmacol.,* **25,** 323 (1973).

28) J.W. LYONS, L. KOTIN. *J. Am. Chem. Soc.* **86,** 3634 (1964).

29) Official Journal of the European Communities (20.12.1973). No. C 112, Second Part, Chapter 1.

Determination of Hg in Various Matrices by Atomic Fluorescence Spectrometry

P. Cavalli, G. Rossi

Introduction

In connection with both the Environmental Pollution and the CBR programmes and as a consequence of the increasing interest in accurately assessing mercury concentration data, the need to determine this element in matrices of variable nature and at concentrations very often below the part per million level made it necessary to design and set up a general procedure to be used on a routine basis.

Although flameless atomic absorption spectrometry in combination with the cold vapour generation technique is the most widely recognized method of carrying out these determinations, atomic fluorescence spectrometry has some unique characteristics which make this technique more attractive for routine applications.

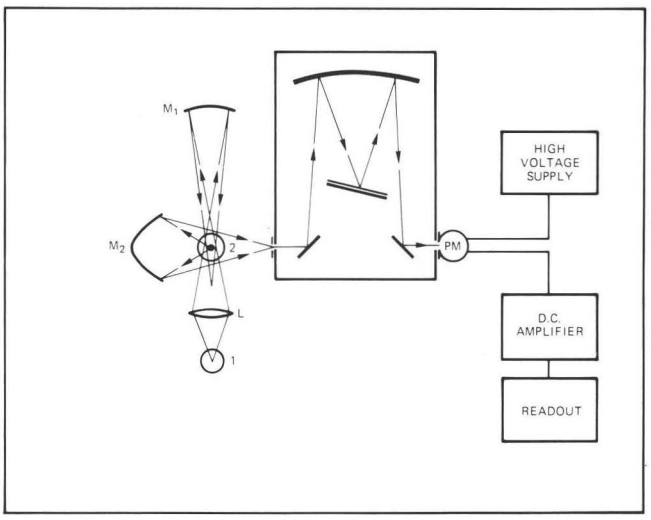
For example, compared to atomic absorption, atomic fluorescence requires much simpler and less expensive intrumentation, exhibits a wider dynamic range because of the linear relationship between the fluorescence signals and the concentration of the fluorescent species, has a sensitivity which is not limited by the Lambert-Beer law but only by instrumental factors and, lastly, exhibits less tendency towards interference by spurious vapours.

On the basis of previous experience in Hg determination by flameless atomic absorption [1] and of the applications of atomic fluorescence to this problem as described in the literature [2-4] it was concluded that this latter technique could meet all the requirements, in particular as to sensitivity, if used with a better-designed fluorescence cell, a significantly improved light-gathering system, and a Hg vapour-generating system such that the fluorescence peak shapes would not be dependent on the nature of the sample (liquid or solid). In other words, the Hg vapours to be introduced into the fluorescence excitation area should be generated and transferred in a single, reproducible way.

Experimental

Apparatus

Fig. 1 shows a diagram of the instrumental set-up. The light emitted by a 90 W Philips low pressure Hg vapour discharge lamp is focused by a short-focus quartz lens in front and at a distance of 5 cm from the entrance slit of a 10 cm focal length monochromator (Spex Micromate). In order to increase the excitation energy, a spherical mirror (M_1) placed on the same optical axis, reflects the incident radiation back into the excitation area. An ellipsoidal mirror (M_2) with two foci is placed in front of the entrance slit of the monochromator, the first focus being placed at



1 Hg vapour discharge lamp
2 Windowless cell
L Focusing lens
M_1 Spherical mirror
M_2 Ellipsoidal mirror

Fig. 1 : Diagram of the instrumental set-up

the centre of the excitation area and the second one coinciding with the monochromator entrance slit. The dimensions and the characteristics of this optical system, along with details concerning its effectiveness in increasing the fluorescence signal, have been presented in a previous paper [5].

The fluorescence intensity at 253.7 nm isolated by the monochromator is monitored with a photomultiplier (RCA IP28) and associated electronics (DC amplifier Keithley 414 S and Hewlett-Packard 7127 A strip chart recorder).

It should be pointed out that the use of a monochromator is not essential for the best results to be obtained; a non-dispepsive system based on an interference filter peaked at the fluorescence wavelength is probably the most convenient basis for this type of measurement. In fact, slit-width studies on the signal and on the signal-to-background ratios led to the results graphically represented in Fig. 2. Fluorescence signals were found to be linearly increasing with the monochromator band pass, while the signal-to-background ratio tends to stabilize at full slit width (2000 μm). In practice the use of an interference filter having an equivalent band pass coupled with a solar blind photomultiplier should allow the same results to be obtained. With the present equipment, a slit width of 1000μm corresponding to a band pass of 8 nm was selected.

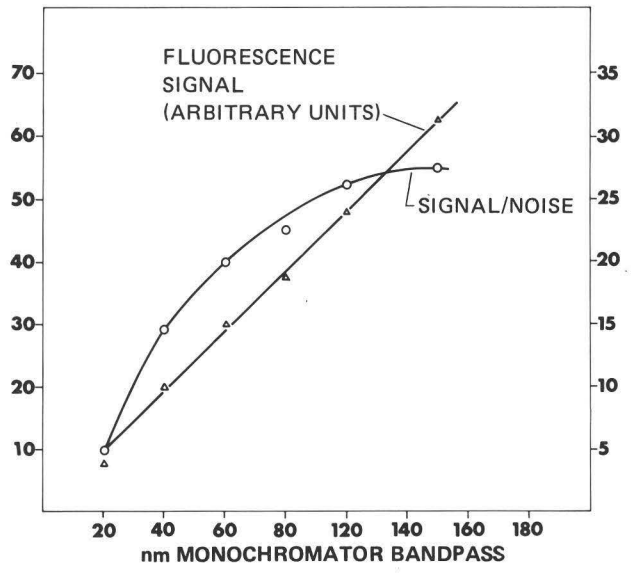


Fig. 2 : Variation of 20 ng Hg fluorescence intensity and of the related signal-to-noise ratio with increasing monochromator band width

Under these conditions, a signal-to-background ratio of about 23 was obtained on sweeping 20 ng of Hg into the excitation area.

The Fluorescence Cell

Muscat and Vickers [3] used a pyrex vapour cell, with vycor windows, inside which the fluorescence excitation process takes place; it was felt, however, that the arrangement described by Thompson and Reynolds [4] consisting of a simple pyrex tube connected to the Hg vapour generation system would be more attractive because of its better suitability to the chosen optical system. Moreover, there is no opportunity for the excitation light beam to be scattered to any extent into the monochromator, and there are no optical windows to be fogged by vapours. Lastly, the recorded fluorescence signal should have a more regular peak shape because of the shorter residence time of the Hg vapour in the excitation area. Since air strongly depresses the fluorescence signal, however, owing to the quenching of the excited Hg atoms mainly by oxygen, and to a lower extent, by nitrogen molecules, greater efficiency could be expected if mixing of the argon-entrained Hg vapours with air could be avoided in the excitation area.

Consequently, after a series of tests with different geometries, the Hg vapour sprayer (Fig. 3) incorporating a gas shielding system was utilized in this study. It is made of black-painted perspex. With the geometry shown, laminar flow is obtained for both the shielding gas and the argon carrier, the mixing of the two gas streams taking place some 3 cm above the sprayer tip, provided that the flow of the shielding gas is kept in the range of 5 – 7 l/min at a pressure of 1.8 to 3.5 atm.

The effectiveness of the gas shielding is clearly borne out from the working curves obtained without gas shielding and with He, N_2 and Ar as shielding gases, Ar always being used as the Hg vapours carrier (Fig. 4). When Ar was used as the shielding gas, a 28-fold increase of the fluorescence signal was obtained.

The effects of the pressure and flow-rate of the Ar carrier gas on the fluorescence signals were carefully investigated in order to establish the most appropriate working conditions. Higher fluorescence signals were obtained by increasing the Ar flow rate; however, steeper curves are produced by decreasing the gas pressure (Fig. 5). This behaviour could be related to the particular procedure used for transferring the Hg vapours to the fluorescence cell (to be discussed in the next section) and to the more concentrated (undiluted with Ar) cloud of Hg vapours subjected to the excitation process when lower Ar pressures are used. An Ar pressure of 0.1 atm at a flow rate of 3 l/min was chosen for all the subsequent experiments.

Hg Vapour Generation

When solid samples are to be analysed for Hg content, two basic procedures are generally employed, i.e. oxidizing combustion of the samples and trapping of Hg on a suitable amalgamator (Au or Ag), or dissolution of the samples followed by the tin (II) reduction method. The merits and disadvantages of both these procedures have been exhaustively discussed in the literature [6-19].

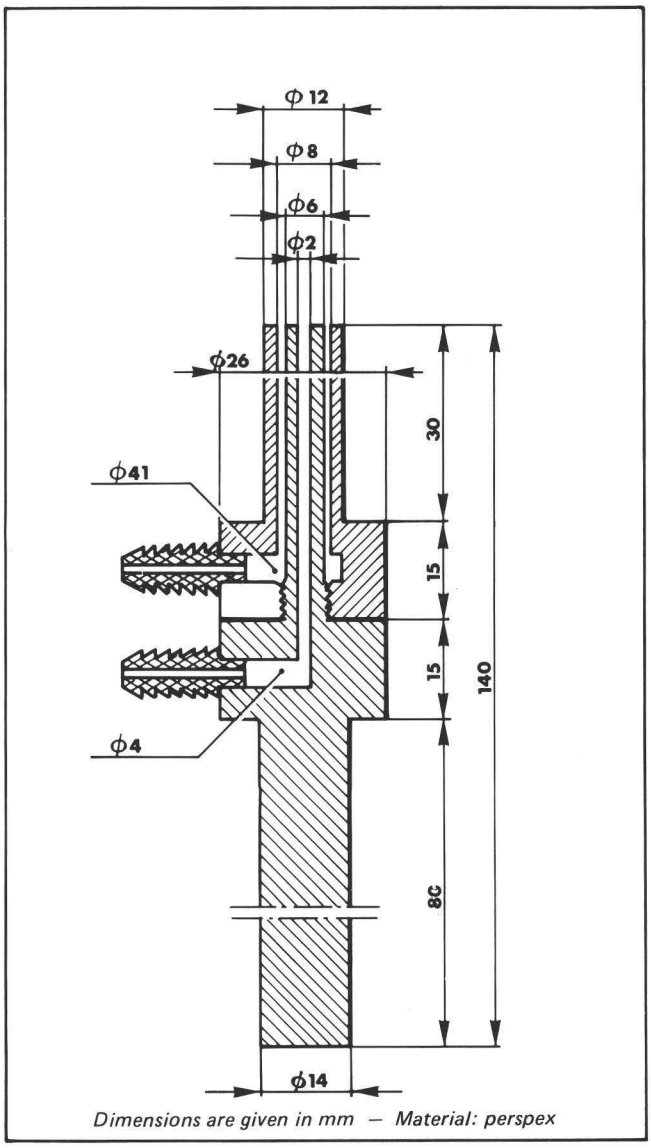


Fig. 3 : Gas-shielded mercury vapour sprayer

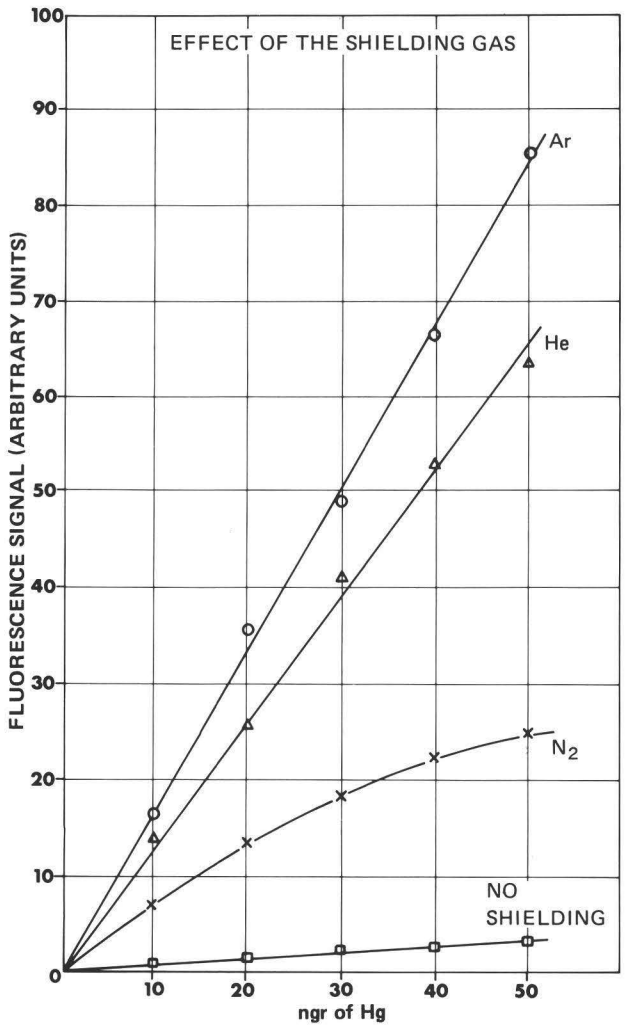


Fig. 4 : Effect of gas shielding on Hg fluorescence intensities

On the basis of extensive investigations carried out in this laboratory, it was concluded that by the first procedure interfering substances can be trapped on the amalgamator, causing incomplete Hg recovery or spurious signals particularly when atomic absorption is used as the measurement technique. On the other hand, Hg losses have been experienced during the dissolution of samples for which heating is required, or blank values by far exceeding the Hg concentrations sought are likely to be introduced by the rather large amounts of different reagents introduced during the whole chemical procedure. Moreover it should be added that each of the procedures described in the literature has been specifically developed for a particular class of sample and cannot be considered as being applicable generally.

The procedure established in this laboratory is a combination of both the combustion and the dissolution techniques, but it minimizes the difficulties discussed above.

A solid sample placed in a platinum boat is burnt in an oxygen stream in a quartz tube heated externally by a tubular oven. The combustion gases are first passed over hot platinum wires to help oxidation and subsequently condensed in a liquid-nitrogen cooled glass trap in a similar manner to that described by Aston and Riley [20]. Obviously, depending on the nature of the sample, combustion conditions must be varied in such a way as to ensure complete oxidation of the sample. For instance, a CuO section in the combustion train may be required for organic-base materials. The trap is brought to room temperature and the condensed substances are dissolved by adding 10 ml of 10% high purity HNO_3. Continuous stirring and heating at 70°C of the solution for 10 minutes is recommended.

The resulting solution is then subjected to the tin (II) reduction aeration procedure to liberate the mercury vapour, Ar being used as carrier gas. Fig. 5 shows a diagram of the mercury vapour generation system. The gas stream is dried by passing it through a $CaCl_2$-$Mg(ClO_4)_2$ packed U-tube and the Hg vapour is collected on an Au amalgamator while other volatile compounds go to waste.

After complete extraction of Hg from the solution (about 4 minutes of Ar bubbling), the amalgamator is further flushed with Ar for 1 minute to complete cleaning. The reaction flask is isolated from the gas line by means of a by-pass system during this time. Then the gas flow is stopped and the amalgamator is heated at 700° in a tubular oven for two and a half minutes. The heating time has been found to be critical if the greatest reproducibility is to be obtained. The gas flow is then restarted and the Hg vapour cloud generated in the amalgamator is swept instantaneously into the windowless fluorescence cell.

In this way a minimum dilution of Hg vapour with Ar takes place, as is demonstrated by the sharpness and the absence of any tailing of the peak recorded. Typical peaks corresponding to various Hg concentrations are shown in Fig. 6. The mechanism of vapour transfer also explains the role played by the pressure and flow of the carrier gas as well as by the shielding gas.

With the exception of the combustion step, the same procedure is applied to the analysis of liquid samples.

Results and Discussions

Working curves were obtained using aqueous mercury standard solutions freshly prepared from a 1000 µg/ml Hg (II) stock solution. Both the stock and the diluted Hg solu-

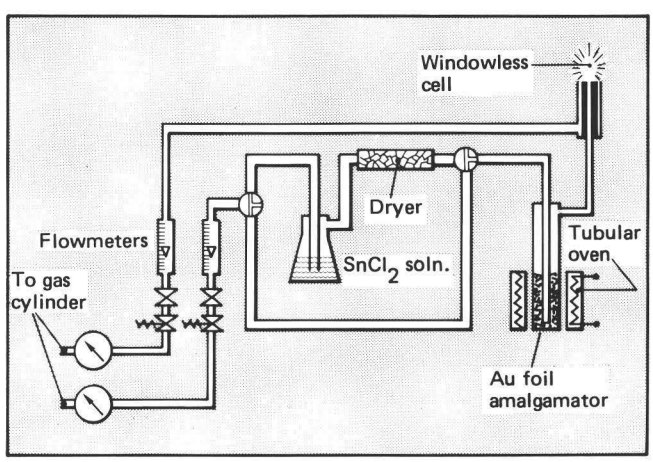


Fig. 5 : Diagram of the mercury vapour generation system

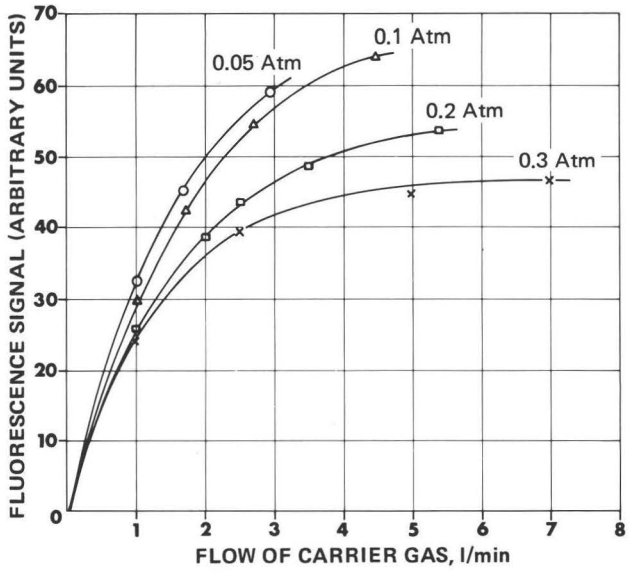


Fig. 6 : Variation of 10 ng Hg fluorescence intensity with Ar carrier flow-rate at different gas pressures

tion were acidified with a few drops of high purity HNO_3. 200 µlt aliquots of the standard solutions were directly introduced into the reduction-aeration flask together with 50 ml of bidistilled water and 5 ml of a 10% (w/v) solution of tin (II) chloride in 2 M HCl in such a way as to cover a Hg content range from 0 to 100 ng. Before the addition of the Hg standard solutions, the tin chloride solution contained in the reaction flask was purged with Ar for 4 minutes to eliminate blanks associated with the chemicals used.

Alternatively, the same Hg standard solutions were placed in the platinum boats and passed through the same procedure used for the real samples.

The two calibration procedures gave coincident values resulting in a linear working curve. This fact indicates that the combustion and the vapour cold-trapping technique did not introduce measurable Hg losses.

In order to evaluate both the accuracy and the applicability of the proposed procedure, two standard reference materials from the National Bureau of Standards were analysed. These have certified Hg concentration and completely different matrices. Five replicate determinations were carried out on each sample using different weights, with the results shown in Table 1.

Table 1 : Comparison of flameless atomic fluorescence data with NBS values for Hg determination in 2 NBS SRM

Sample	Replicate	Sample weight mg	Hg (ppm)	NBS value
NBS	1	130.7	0.141	
SRM 1571	2	129.3	0.139	
	3	112.6	0.152	
Ochard	4	131.0	0.152	
leaves	5	136.5	0.145	
			mean value	
			0.146	
			S 0.006	0.155
NBS	1	105.2	0.121	
SRM 1630	2	345.9	0.108	
	3	207.5	0.134	
Trace mercury	4	105.0	0.119	
in coal	5	210.4	0.107	
			mean value	
			0.118	(0.11)*
			S 0.011	

* *New value recently set by NBS (21)*

Sensitivity and Precision

The limit of detection expressed as three times the standard deviation of the noise associated with the signal was equivalent to 0.03 ng. In practice, Hg determinations below 0.5 ng could not be performed, this limit being set by a blank value which could not be eliminated and not by instrumental limitations. This blank was estimated to be 0.25 ng Hg. The relative standard deviation calculated from a series of ten replicate determinations of 20 ng Hg (aqueous standard solution) was found to be 4.5%. However, it must be stressed that the reproducibility is almost independent of the Hg concentration. In fact, equivalent signal variations were observed for Hg concentration both below and above 20 ng.

Conclusions

The described method has now been used for two years in this laboratory for Hg determinations in a wide-ranging variety of samples including rocks, sediments, sewage waters, plants and vegetables, etc., showing its applicability for routine survey.

Taking into account the very high sensitivity which has been obtained, precautions must be taken to operate the

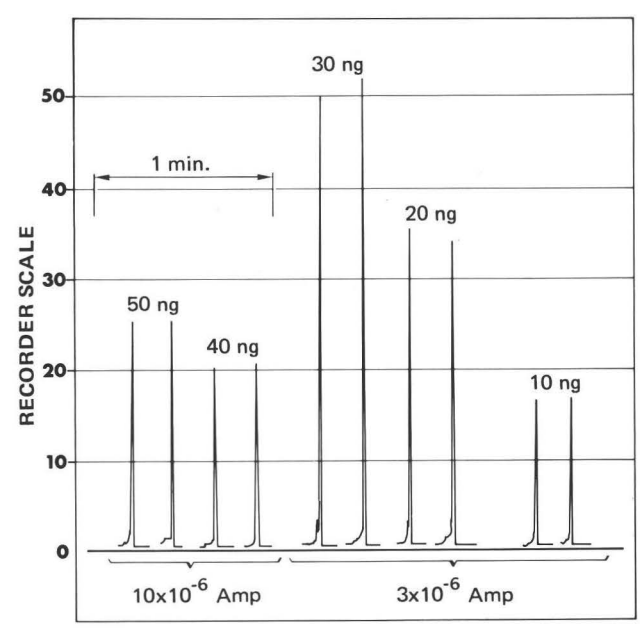


Fig. 7 : Recorder tracing of fluorescence signals at various Hg concentration levels

instrumentation under carefully controlled environmental conditions to minimize any possibility of Hg contamination.

Summary

An application of atomic fluorescence spectrometry is described for Hg determination at the ng level. Solid samples are burnt in an oxygen stream, the combustion gases being condensed in a liquid nitrogen-cooled trap. Following the dissolution of the condensed matter, Hg is extracted by the reduction-aeration method and collected on a Au amalgamator. The combination of a high-efficiency light-gathering system with a gas-shielded windowless fluorescence cell and with a particular procedure for the release of Hg vapour from the amalgamator permits a detection limit of 0.03 ng to be obtained. A linear working curve covering the Hg concentration range from 0.5 to 100 ng was established with aqueous Hg standard solutions.

The whole procedure has been checked with two different NBS Standard Reference Materials, an excellent fit of the measured values with those certified being found.

References

1) G. ROSSI, E. ORTHMANN-ROEMER. JRC Ispra Annual Report 1972, EUR 5060 p. 382.

2) V.I. MUSCAT, T.J. VICKERS, ANDERS ANDREN. *Anal. Chem.* **44,** 218 (1972).

3) V.I. MUSCAT, T.J. VICKERS. *Anal. Chem. Acta,* **57,** 23 (1971).

4) K.C. THOMPSON, G.D. REYNOLDS. *Analyst,* **96,** 771 (1971).

5) P. BENETTI, N. OMENETTO, G. ROSSI. *Appl. Spectry,* **25,** 57 (1971).

6) I.K. ISKANDAR, J.K. SYERS, L.W. JACOBS, D.R. KEENEY, J.T. GILMOUR. *Analyst,* **97,** 388 (1972).

7) I. SKARE. *Ibid.*, **97,** 148 (1972).

8) P.C. HEAD, R. NICHOLSON. *Ibid.*, **98,** 53 (1973).

9) A.M. URE, C.A. SHAND. *Anal. Chem. Acta,* **72,** 63 (1974).

10) V. LIDUMS, U. ULFVARSON. *Acta Chem. Scand.,* **22,** 2150 (1968).

11) J.A. GOLEB. *Appl. Spectry,* **25,** 522 (1971).

12) J.V. O'GORMAN, N.H. SUHR, P.L. WALKER Jr. *Ibid.,* **26,** 44 (1972).

13) H.G. HENRY, K.R. STEVER, W.L. BARRY, H.H. HEADY. *Ibid.,* **26,** 288 (1972).

14) R.J. THOMAS, R.A. HAGSTROM, E.J. KUCHAR. *Anal. Chem.,* **44,** 512 (1972).

15) T.C. RAINS, O. MENIS. *Jaoac,* **55,** 1339 (1972).

16) W.A. WILLFORD, R.J. HESSELBERG, H.L. BERGMAN, *Ibid.,* **56,** 1008 (1973).

17) H. AGEMIN, A.S.Y. CHAU. *Anal. Chem. Acta,* **75,** 297 (1975).

18) O.I. JOENSUU. *Appl. Spectry,* **25,** 526 (1971).

19) E.W. BRETTHAUER, A.A. MOGHISSI, S.S. SNYDER, N.W. MATHEWS. *Anal. Chem.,* **46,** 445 (1974).

20) S.R. ASTON, J.P. RILEY. *Anal. Chem. Acta,* **59,** 349 (1972).

21) NBS Private Communication.

Part 3

THE SUPPORTING ACTIVITIES

Introduction to the Site Directorate

H. Niemeyer

As a direct result of the Pluriannual Research and Development Programme decided upon by the Council in the first half of 1975, the Administration and Financial Services were, during 1974 and 1975, one of the chief objects of reorganisation and rationalisation within the management of the research centre.
The new Directorate took over in early September 1974.

As far as the Administration and Financial services were concerned, the new orientation, which went into force immediately the reorganization was implemented, meant achieving a better balance between the staff, the infrastructure (supporting services) and the research programme itself.

The main problem, which had to be tackled first, was to reduce the social tensions which had developed over a considerable period of time. This was done through many discussions and negotiations with representatives of the staff.

For the Financial sector, 1974 and 1975 represented the 2nd and 3rd years of the pluriannual research and development programme, during which the credit and debit composition of the structure hardly differed from that of the previous year. The general evolution of costs (inflation) during the financial year 1975 therefore made some economy measures necessary, and finally necessitated a supplementary allocation which was ratified towards the end of the financial year.

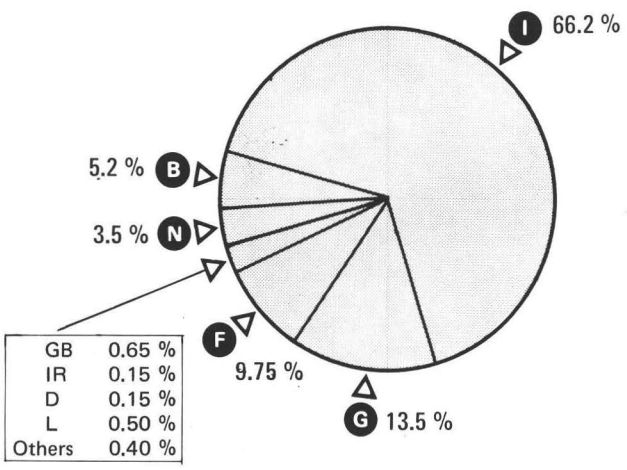
Administration and Personnel

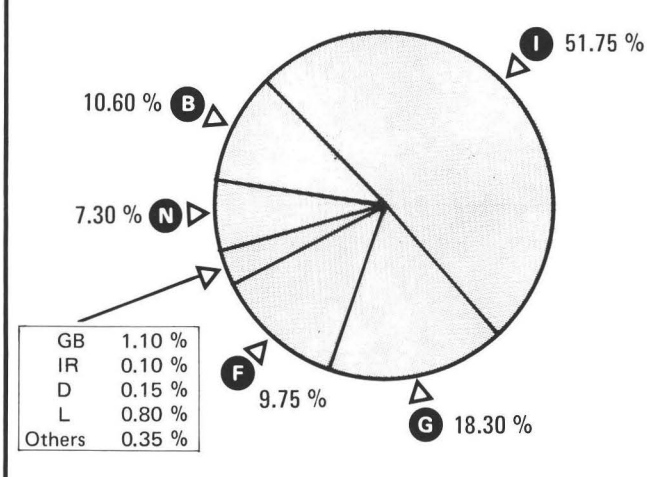
A. de Briey

Personnel

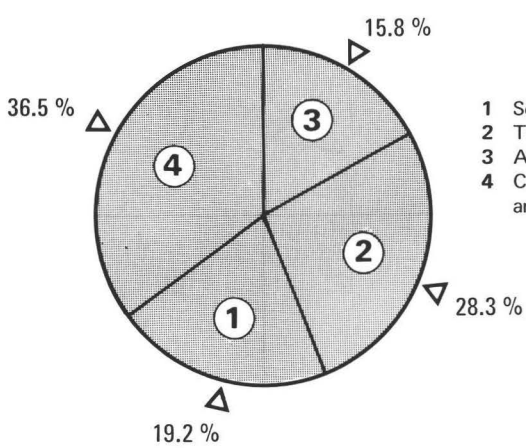
On 31st December 1974, the staff of the JRC Ispra Establishment totalled 1269 and the number of locally employed personnel and auxiliary staff totalled 406. During the year 1975 there was a small staff reduction, the total of officers being 1266 plus 403 locally employed staff. Detailed distribution of the personnel by nationality and profession is given in the graphs below.

1974

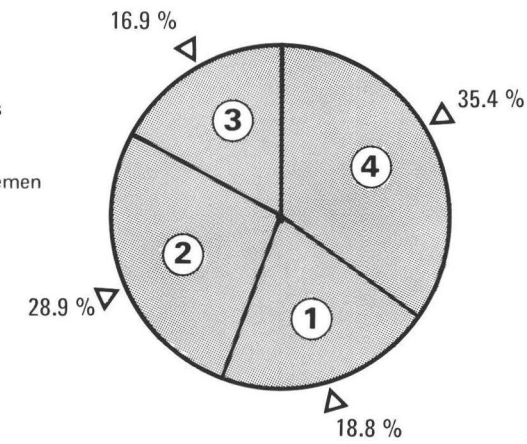




Breakdown by Nationality
(including AE and locally employed personnel)

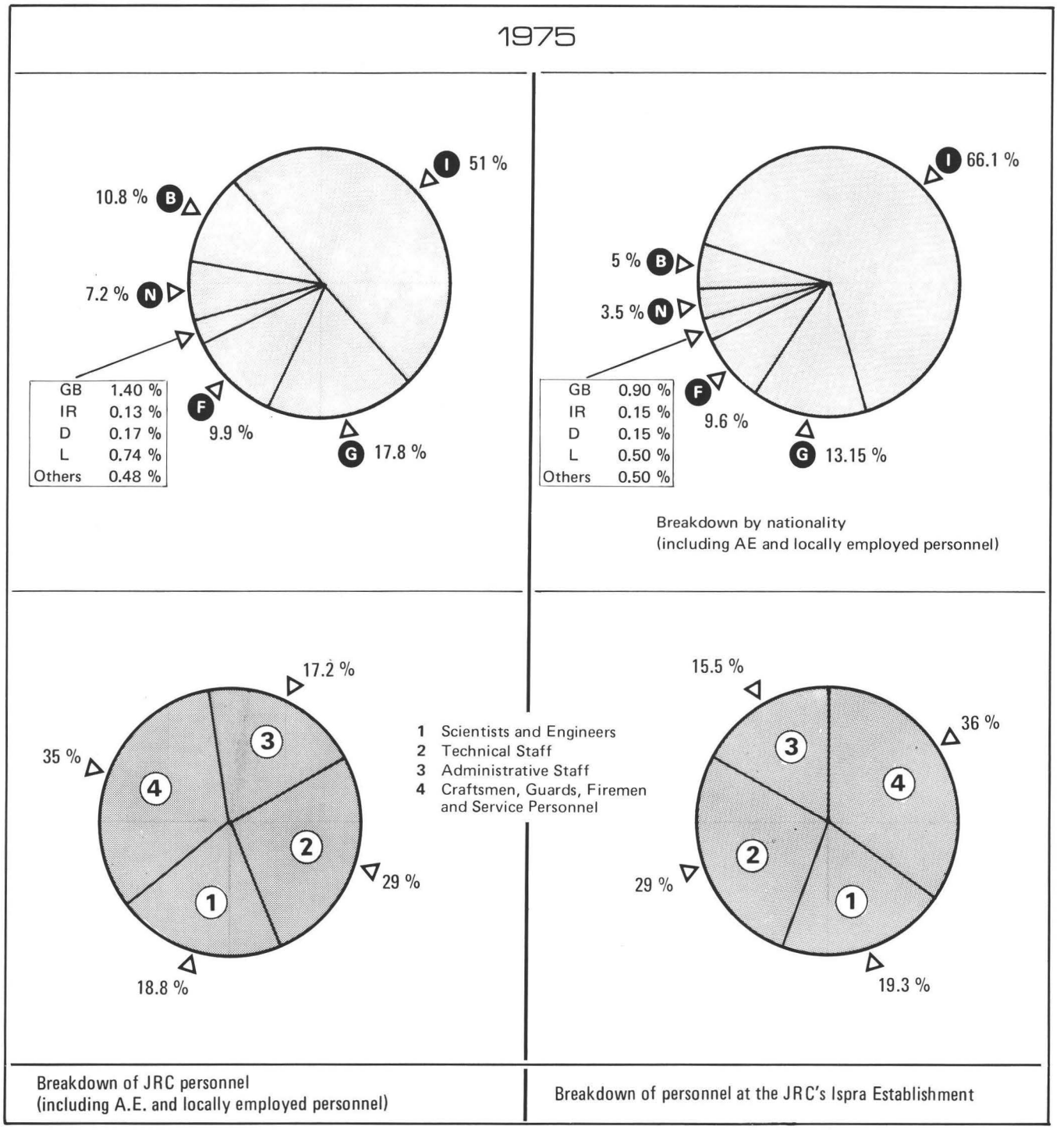


1 Scientists and Engineers
2 Technical Staff
3 Administrative Staff
4 Craftsmen, Guards, Firemen and Service Personnel



Breakdown of personnel at the JRC's Ispra Establishment

Breakdown of JRC personnel
(including A.E. and locally employed personnel)



Staff Training

Technical Improvement Courses

During the academic year 1973-1974 three courses were organized at Ispra within the framework of the CNAM courses. The corresponding examinations led to 12 certificates.

"Calculus of Probabilities and Mathematical Statistics B"
"Numerical Analysis B 1"
"Numerical Analysis B 2"

During the following academic year 1974-1975 five courses were organized at Ispra within the framework of the CNAM courses:

"Calculus of Probabilities and Mathematical Statistics B"
"Information Processing and Programming A"
"General Mathematics A"
"Statistics Technique A"
"Decision Theory (First Part)".

Participation in External Training Activities

In 1974, 154 people, and in 1975 119 people, participated in external activities including short periods in specialized laboratories, general correspondence courses and specific courses of technical and academic level.

Language Courses

361 staff members attended English, German, French or Italian courses taught in Ispra during 1975.

Personnel breakdown by services and by categories (administrative and scientific) at the JRC Ispra Establishment (including locally employed personnel)

31 - 12 - 74

Services	A	B	C	D	Total (1 to 4)	E + F	Total (5 + 6)	G	Others	Total (7 to 9)
	1	2	3	4	5	6	7	8	9	10
Directorate, Ispra Establishment	4		1		5	3	8			8
Director, Future Programmes	1	1			2		2			2
Future Programmes	3	1			4		4			4
Director, Dept. A	2	1			3		3			3
Director, Dept. B	4	2			6		6		1	7
Prov. Secretariat CBR	3	2			5	1	6			6
Director, Dept. C	2		1		3		3			3
Directorate, General Service	1	1			2		2			2
Organic Information System	1	1			2		2			2
Public Relations		2	2		4	2	6	1		7
Administration & Personnel	3	14	13		30	22	52	60	4	116
Finances & Supply	5	12	3		20	19	39	20	2	61
Accounting	2	3	1		6	5	11	2	3	16
Design & Fabrication	8	39	29		76	66	142	25		167
Infrastructure	4	12	1		17	43	60	108		168
Protection	7	15	1		23	25	48	19		67
Security		5			5	19	24	16		40
Local Personnel Committee			2		2		2	1		3
Scientific Directorate	6		3		9	1	10	1	1	12
Biology	3	1			4	1	5	1		6
CETIS	38	44	4		86	12	98	13		111
Chemistry	46	56	3		105	31	136	36	2	174
Nuclear Studies	15	6			21	1	22	1		23
Materials	41	64	2		107	19	126	18		144
Physics	40	22	5		67	5	72	1		73
Technological Studies	55	82	9		146	29	175	28		203
Technology - Electronics	18	26	1		45	9	54			54
ESSOR	22	72	9		103	48	151	41	1	193
TOTAL	334	484	90		908	361	1,269	392	14	1,675

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Services	A	B	C	D	Total (1 to 4)	E + F	Total (5 + 6)	G	Others	Total (7 to 9)
	1	2	3	4	5	6	7	8	9	10
Directorate Establishment	2	1	2		5	2	7	1		8
Director, Future Programmes										
Technical Studies	4	1			5		5	1		5
Planning & Resources	2				2		2			2
Director Approved Programmes	8		1		9		9			9
Director Dept. A	4	11	2		17	8	25	8	1	34
Information Service	7	19	2		28	6	34	10		44
Applied Informatics	21	13			34	1	35	2		37
Systems Analysis	25	10	1		36	4	40	1		41
Director Dept. B	6	2	2		10	1	11	2		13
Applied Mechanics	14	27	1		42	6	48	16		54
Heat Exchange	22	35	9		69	18	85	12	1	98
Process Engineering	17	24	2		43	4	47	5		52
Electronics	16	26	1		43	8	51			51
ESSOR	23	73	11		107	43	150	40	1	191

Design & Fabrication	7	38	24		69	56	125	22		147
Biology	3	1	24		4	1	5	1		5
Prov. Secretariat CBR	3	2			5	1	6		1	7
Director Dept. C	2	1	1		4	1	5			5
Physics	41	21	7		69	4	73	1		74
Chemistry	42	64	3		109	28	137	37	2	175
Materials	38	63	1		102	20	122	17		139
Directorate, General Service	5	1			6		6	2		8
Organic Information System										
Public Relations	1	1	2		4	2	6	1		7
Administration & Personnel	6	15	10		31	20	51	60	4	115
Finances & Supply	4	15	3		22	18	40	20	2	115
Accounting	2	3	2		7	4	11	3	2	15
Fabrication and Design										
Infrastructure	4	14	2		20	38	58	112		170
Protection	6	15	1		23	24	47	17		54
Medical Service										
Security		5			5	19	24	16		40
Local Personnel Committee			1		1		1	2		3
TOTAL	335	503	91		929	337	1.266	409	14	1.689

Social Affairs

Housing

The rate of occupancy of the housing available remained at a steady 95% through out 1974 and 1975. The undergraduate and postgraduate students occupied between 45 and 50% of the furnished housing available.

The reception office dealt with 637 missions in 1974 and with 645 missions in 1975, and 14 permanent staff members were temporarily accommodated during 1974 and 24 during 1975.

The number of guests/visitors who made use of our hostelry was 571 in 1974 and 583 in 1975, representing 1230 and 1447 man/nights respectively.

Social Assistance

The total number of attendances of children at the Day Care Centre increased by 33% with respect to those of 1974. The average frequency of attendance was 47 during 1975.

In 1975 a school building was added to our facilities by the departure of the European School from Ispra to its new buildings in Brebbia.

The new Day Care Centre for children up to 3 years is nearing completion and will probably function in the beginning of 1976.

The holiday centres organized by the Commission were slightly less well-attended: 429 children participated against 456 in 1974. Owing to rising costs the subsidy spent on this activity mounted to 37.500 u.a. (against 34.000 u.a. in 1974).

During 1975 the personnel situation of the Social Assistance Office improved for a period of 6 months, because of the presence of an auxiliary social worker. The activities remained reduced, especially during 1974, to emergencies, running the Day Care Centre and holiday homes.

Canteen and Club House

The number of meals served in 1974 was 227,861 with a monthly average of 18,900 meals and low and high limits of 12,947 and 23,828 respectively. For 1975 these figures were 202,109 total, monthly average 16,842, low limit 9,509 and high limit 23,001.

The Club House continues to offer its facilities to various cultural and sportive activities. Its opening hours had to be reduced in 1975 owing to restrictions on overtime.

Visitors, Students, Fellows – Administration

The breakdown of the number of students present at the Ispra Establishment is given in the following tables for the years 1974 and 1975.

Table 1 : Number of trainees and scholars

	Student trainees		Scholars		Total	
	1974	1975	1974	1975	1974	1975
Present on the 1st of January	12	26	28	38	40	64
Arrived during the year	45	38	16	17	61	55
Total of those present	57	64	44	55	101	119
Contract ending in the period from the 1st of January to the 31st of December	32	36	10	30	42	66
Present on the 31st of December	25	28	34	25	59	53

Table 2 : Break-down by nationality and division, trainees and scholars

1974	BNL		D		F		GB		I		IR/DK		OTHERS		TOTAL	
	st.	sch.	st.	sch.	st.	sch.	st.	sch.	st.	sch.	st.	sch.	st.	sch.	st.	sch.
Biology	5	4	-	1	-	-	1	2	6	-	-	-	-	-	12	7
CETIS	-	1	1	3	-	1	-	-	7	4	-	-	-	-	8	9
Chemistry	1	3	-	-	1	-	-	-	2	3	-	-	1	-	5	6
Nuclear studies	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Materials	1	-	2	2	1	1	-	-	2	1	-	-	-	-	6	4
Physics	-	1	1	5	-	-	-	-	5	-	-	-	-	1	6	7
Technology	6	1	-	4	1	1	-	1	8	2	-	-	-	-	15	9
Electronics	2	1	-	-	-	-	-	-	1	1	-	-	-	-	3	2
Others	-	-	-	-	-	-	-	-	2	-	-	-	-	-	2	-
Total	15	11	4	15	3	3	1	3	33	11	-	-	1	1	57	44

1975	BNL		D		F		GB		I		IR/DK		OTHERS		TOTAL	
	st.	sch.	st.	sch.	st.	sch.	st.	sch.	st.	sch.	st.	sch.	st.	sch.	st.	sch.
Biology	4	1	-	-	-	1	1	1	8	-	-	-	-	1	13	4
CETIS	2	-	-	4	-	2	-	1	8	3	-	-	2	-	12	10
Chemistry	3	1	-	-	1	-	-	-	5	3	-	-	-	5	9	9
Nuclear studies	-	-	-	-	-	-	-	-	2	-	-	-	-	-	2	-
Materials	-	1	-	2	-	1	-	-	3	-	-	-	-	-	3	4
Physics	1	2	-	5	-	-	-	-	13	-	-	-	-	1	14	8
Technology	2	3	2	5	-	1	-	-	5	2	-	-	-	1	9	12
Electronics	1	-	-	-	-	-	1	-	2	1	-	-	-	1	4	2
Others	-	-	-	-	-	-	-	-	3	-	-	-	-	1	3	1
Total	13	8	2	16	1	5	2	2	49	9	-	-	2	10	69	50

Table 3 : Number of students present expressed in man-months

1974	BNL		D		F		GB		I		IR/DK		OTHERS		TOTAL	
	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH
Scholars	11	103	15	138	3	36	3	19	11	88	-	-	1	12	44	396
Student trainees	15	83	4	18	3	9	1	4	32	227	-	-	2	9	57	350

	BIOLOGY		CETIS		CHEM.		NUC.ST.		MATER.		PHYSICS		TECHN.		ELECTR.		OTHERS		TOTAL	
	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH
Scholars	7	60	9	75	6	58	-	-	4	38	7	69	9	76	2	20	-	-	44	396
Student trainees	12	60	8	56	5	26	-	-	6	30	6	49	15	103	3	16	2	14	57	354

1975	BNL		D		F		GB		I		IR/DK		OTHERS		TOTAL	
	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH
Scholars	4	47	9	94	2	24	2	24	8	96	-	-	1	6	26	291
Student trainees	13	58	3	15	3	9	1	4	26	265	-	-	-	-	46	551

	BIOLOGY		CETIS		CHEM.		NUC.ST.		MATER.		PHYSICS		TECHN.		ELECTR.		OTHERS		TOTAL	
	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH	NP	NH
Scholars	7	57	12	84	11	88	-	-	3	23	7	40	11	95	3	18	1	9	55	414
Student trainees	10	71	10	46	7	31	2	22	4	29	15	94	10	64	3	22	3	21	64	400

Finance and Supply Division

K. Fuelster

The **Budgetary Administration** was carried out by the Finance and Supply Division in close collaboration with the Directorate of Forecasting Studies. This activity involved:

- regularizing provisional booking operations carried out while awaiting programme decisions;
- establishing the 1974 and 1975 Sections of the Budget;
- preparing the 1976 Budget within the framework of the 4-year programme decided upon by the Budgetary Authority.

The **Financial Administration** of the Establishment was carried out by the Finance and Supply Division. This activity involved:

- the administration of contracts, including contracts for the provision of services and conventional contracts,
- the administration of insurance policies for conventional risks (fire, motor third-party liability, etc.), liability of the Centre towards its personnel and visitors, and public liability of the Centre for nuclear risks and transport of fissile and radioactive materials,
- the Central Stores, for administrative and scientific materials, with an Urgent Purchases Office in Milan,
- the Acceptance and Customs Office, for the customs clearance and technical reception operations for materials entering the Centre,
- the Secretariat of the Advisory Committee for Purchases and Contracts,
- the Local Inventory Office for recording of inventionable items.

Infrastructure

F. Sciuto

As in previous years the Construction and Infrastructure Division has continued its work concerning air conditioning equipment, water and power supplies and telecommunication facilities; in addition, the Division has done any necessary maintenance work and carried out modifications within the limits of the available funds.

In 1975 the JRC was granted an allocation of 1,244,000 u.a. for safety measures, which made it possible to remedy some of the Centre's more important shortcomings in that field (protection against water hammer at the pumping station, protection of installations and personnel at the electrical substation, protection against radiation following conversion of a laboratory for radio-chemistors, improved treatment of drinking water, better safety on boilers and the lines connected to them, etc.). The principal work done is described in detail below.

Electricity and Telephones

The main feature of the divisional activity in 1974 was the altering of the power sub-station and completion of the first transformer bank, which can now receive a tension of 130 kV instead of the former 45 kV. When carrying out this particular task the Division had to overcome considerable technical and administrative obstacles since the work had to be done without causing any interruption in the power supply.

In 1975, the electrical fittings were installed in the new Nursery School, and work began on the construction of the second 130 kV transformer bank for the sub-station. The installation of emergency alarm circuits in the technical galleries was completed.

During 1974-1975 various items of equipment were installed or modified to meet the requirements of the research sections.

Considerable labour and material were employed to keep numerous installations working which are so old that they perpetually require increasingly expensive maintenance. In the field of telecommunications several problems were tackled and to some extent solved, thus allowing greater flexibility in the use of such facilities.

The new IBM 3750 System (telephone switch, data collection and EDP) was installed and became operative in 1975 with the cooperation of CETIS.

Hydrothermal Installations

The following is a list of the main work done on the various distribution networks:

Lake-water supply: Replacement of the three buffer tanks at the pumping station; filter circuit modification to improve distribution of industrial and drinking water.

Drinking water: Replacement of nine electrolytic cells producing chlorine for the water supply station.

Superheated water: Brick-work to renew inner liners of Boilers 1 and 2; construction of an air intake pre-heater for Boiler 3.

Waste water: Construction of a Venturi meter for final sewer discharge channel; start of construction of water-raising system for purification plant.

Refrigerated water: Start of modifications to circuits of the refrigerator-plant absorber system.

For the network as a whole 2,900 m of piping were replaced.

Other important work:

- Design and installation of the air-conditioning equipment for the Asilo Nido (nursery school) and Ispra Courses buildings.
- Replacement of stack; change of the incinerator burners.
- Setting-up of tool rooms for the new divisional workshops.
- New washing facility for air-conditioning filters.
- Maintenance of all heating, water-supply, sanitary and air-conditioning plants.

Design and Construction Work

The Design Section brought existing drawings up to date and did the designing and costing for the following buildings: new Nursery school, bunker for COVA experiment, building for Blowdown project adjacent to building 24 (complete with air-conditioning and internal bunker), enlargement of Garage C 15/a; at 54/b: dressing-room for Hydrothermal Section workers; Ispra Courses hall, new premises for Solar Experiment; D 29/b: air intake; C 46: new radiochemistry laboratory. Furthermore a general survey was made to accomodate Project JET (Joint European TORUS) at the Ispra Joint Research Centre.

The Buildings Section carried out all necessary maintenance on the buildings, roads, parking areas, woods and meadowland.

It provided technicians and masons to carry out various work for the electrical and hydrothermal sections. It also helped in the alterations to the electrical sub-station, laid the foundations for the new transformers, and made all the adaptations and changes requested by the research workers in various Centre premises.

Protection

A. Malvicini

The Protection Division deals with:

- health-physics protection of the employees of the Centre and the population in the close vicinity;
- conventional and nuclear risk prevention;
- countermeasures in case of accidents;
- transportation of radioactive material and book-keeping of fissionable substances;
- the application of safety and radiation protection recommendations.

In addition to these tasks the Division has, during 1974-75, performed various studies and services under contract, and held two radiation protection courses.

Health Physics and Personnel Dosimetry

The main activity of this Section is to protect personnel working in areas with radiation risks (laboratories with radiation danger, hot-cell facilities, reactors). In particular the Section has fulfilled the following functions:

- the evaluation of exposure levels, measurement of air and surface contamination in controlled areas;
- the determination of the individual dose due to external radiation, received by personnel professionally and occasionally exposed to radiation;
- the control and maintenance of health physics instrumentation;
- the film-badge service for the Safeguards Directorate, Luxembourg;
- liaisons with the Local and Central Italian Authorities on radioprotection problems.

The periodic controls and air-activity measurements performed revealed that the admissible levels were in no case exceeded. During 1974/75 no radiation or contamination accidents occurred in which personnel were involved.

A monthly average of about 2000 people were monitored with film dosimeters. Less than 0.1% of the people checked absorbed a dose higher than 1 rem in 1974 and 1975, and less than 0.5% a dose higher than 0.5 rem. During 1974/75 no dose over 5 rems was recorded.

The monitoring of the gaseous radioactive emissions into the atmosphere from the nuclear installations showed that the amounts emitted were well below the limits fixed for the Establishment.

In Autumn 1974 and Spring 1975 the Section organized the scientific side of two series of three radioprotection courses:

"Fundamentals in Radioprotection"
"Radioprotection in Hospitals, Industry and Research"
"Radioprotection in Nuclear Plants"

Site Survey and Radioactivity Measuring Laboratory

The task of this group is to protect the population living around the Ispra Establishment from radiation and to measure the radioactivity of various samples and in persons. To perform this task the following activities were carried out:

- monitoring of atmospheric radioactivity (air and rainwater) by means of the stations located along the boundary of the Establishment;
- control of the radioactivity level in the liquid effluents, performed directly at the source before discharge, and at the monitoring station on the Novellino brook;
- measurements of the radioactivity in water (Lake Maggiore, river Ticino, underground water inside and outside the Establishment) soil, vegetation and foodstuffs in the environment;
- measurements of the radioactivity of various samples from the laboratories of the Establishment;
- measurements of the internal radioactive contamination of employees by means of the human body counter.

The main objective of these measurements is to keep a constant check on the radioactivity levels inside and outside the Establishment. The data obtained through the surveillance programme indicate that, as previously, in the calendar years 1974 and 1975, the environmental radiation exposure in the area around the Establishment was due almost exclusively to natural background and world-wide fallout.

The instrumentation of the laboratory was improved by the acquirement of a Ge(Li)-detector (60 cm^3) for the gamma spectrometric measurements of samples, and of a surface-barrier detector for alpha spectroscopy.

A new NaI(Tl)-detector (8".4") with low-level radioactivity background was put into operation at the total body counter. The measurements taken with this detector provided very useful information about low-level radioactivity in human beings. During the years 1974 and 1975

about 2000 radioactivity measurements were made on employees of the Research Centre and 600 measurements of radioactivity on employees for four external companies. 500 of those measurements refer to the determination of low-enrichment uranium.

Meteorology

During 1974 and 1975 the Meteorology Group was concerned with two principal tasks. The first related to the "routine" of the Nuclear Research Centre (continuous recording of the wind at the Observatory and at the top of the 120 metre-high tower, measurements of other meteorological elements). Apart from the special requirements of the Protection Department itself, many data were supplied to colleagues in other JRC laboratories at Ispra.

The second task, which employed nearly half the working time of the meteorological team, consisted in work performed for third parties under contract. We processed all the meteorological strip graphs which had been recorded at the EUREX plant, and returned them to Saluggia ready for printing as the Annual Meteorological Yearbook.

The hydrography of Lake Lugano was studied, with almost two months of measurements followed by computation; this work constituted a large part of the annual report on "The Eutrophication of an Alpine Lake".

Other Activities

One member of the Division studied secondary standard dosimetry problems and participated as the Commission's representative on the Joint WHO/IAEA Panel on Secondary Standard Dosimetry Laboratory (SSDL) Activities in Rio de Janeiro, Brazil, at the end of the year.

Various feasibility studies were performed concerning the introduction of thermoluminescence dosimetry for routine personnel monitoring. No final conclusions have been drawn from those studies as yet.

Antifire Intervention and Prevention of Conventional Risks

During 1974 and 1975 there were 27 internal fire interventions and 40 external calls for fire intervention.

169 persons were transported by ambulance.

There was a large fire in June in the Solid Physics Laboratory, which burned down completely as a result of the explosion of different gases provoked by a power failure.

For 76 days in June, July and September 1974 the Snorkel was employed in the ricefields for measurements by the Remote Sensing Group. During 1975 the Snorkel was employed in 73 various interventions.

Transport of Radioactive Material

During 1974 and 1974, 20 international transportations of radioactive material were effected by road with trucks and staff of the JRC Ispra. 112 international shipments were organized by air and railway. On Italian territory about 213 transportations of small quantities of radioactive material were made by road with trucks and staff of the JRC Ispra. These movements of materials from Pisa, Pavia, Saluggia, Milan etc. enabled some research groups to continue their work after the closure of the ISPRA-I reactor.

Four lots of irradiated fuel-elements (large sources) were transported, from Ispra to Marcoule (France), from Ispra to EUREX, Saluggia, and from the Garigliano plant to Ispra.

Inside the Centre about 550 transport operations involving radiactive wastes and about 850 involving radioactive substances were carried out.

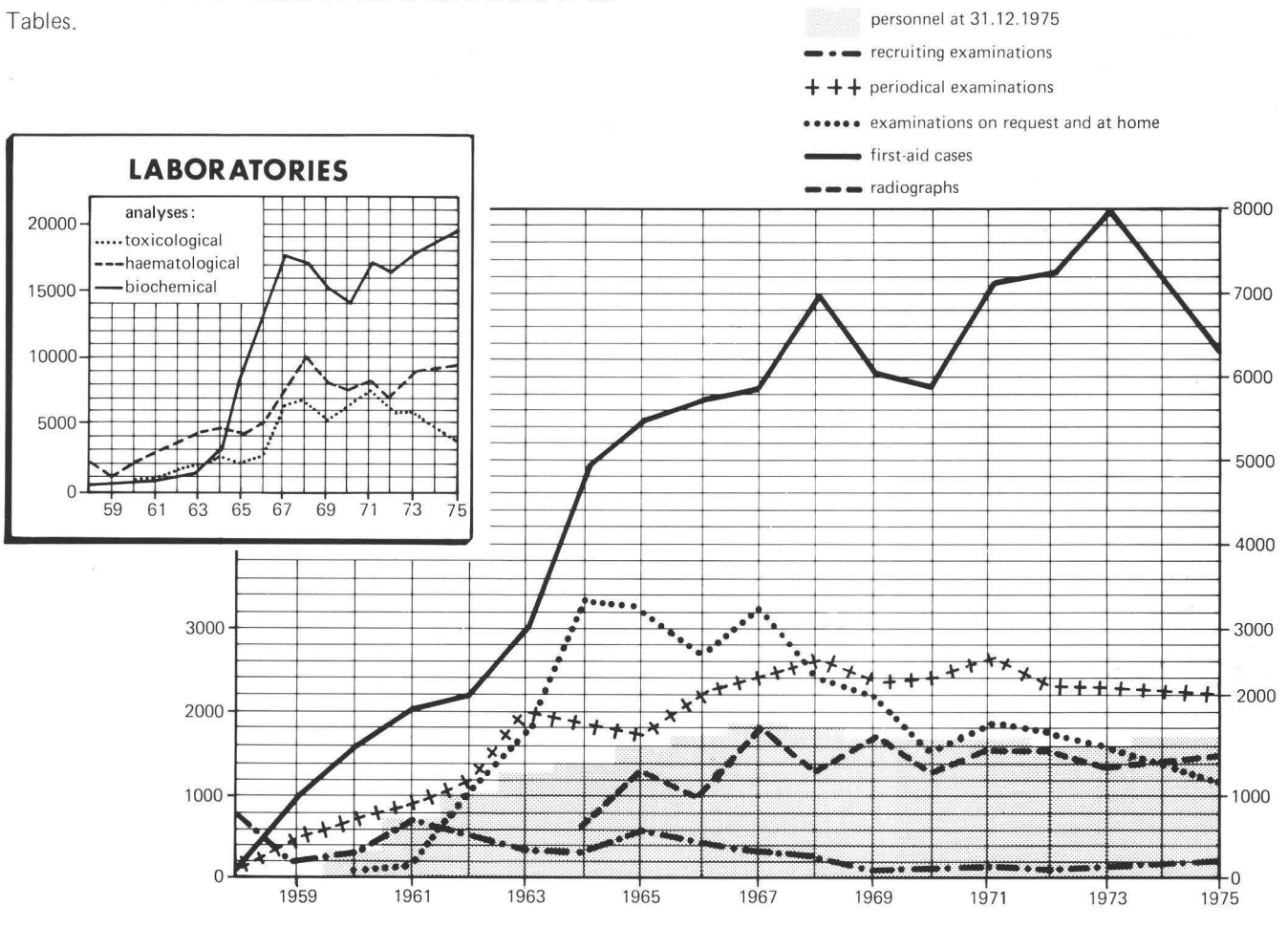
Control and Book-keeping of Fissile Material

Within the Centre there are about 35 tons of nuclear material subdivided into 200 lots. The Section carries out the surveillance and keeps account of this material in conformity with the regulations of Euratom Safeguards and Control, Luxembourg, and of the Italian authorities. To further this work the group lays down internal rules for the different laboratories concerning the movements and the utilization of radioactive materials.

Medical Centre

C. Vigan

The work of the Medical Service is summarized in the Tables.



1974	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Total
Radiotoxicology													
Uranium and Thorium natural	16	-	4	1	23	16	6	1	-	17	-	1	85
Tritium and Carbon 14	80	33	13	266	30	139	74	49	36	359	110	63	1252
Personnel decontamination	-	-	-	-	-	-	-	1	-	-	-	-	1
Radionuclides													
Beta	48	27	22	5	44	7	47	25	13	31	58	25	352
Gamma	48	27	22	5	44	7	47	25	13	31	58	25	352
Alpha	11	-	-	-	16	3	-	1	-	16	1	-	48
Toxicology													
Mercury	6	-	-	-	-	-	4	-	1	9	-	-	20
Polyphenyls	-	-	-	-	-	-	-	-	-	-	-	-	-
Other toxics Pb	-	-	-	-	-	-	-	-	-	8	-	-	8
Sound levels	-	2	-	2	-	-	-	-	-	8	1	-	13

1975		J.	F.	M.	A.	M.	J	J.	A.	S.	O.	N.	D.	Total
Radiotoxicology:														
Uranium and Thorium natural		30	-	1	19	15	33	29	-	6	28	14	3	178
Tritium and Carbon 14		138	121	171	283	71	67	263	244	79	110	273	78	1898
Personnel decontamination		-	-	-	1	-	-	-	-	-	-	1	-	2
Radionuclides:	Beta	58	46	53	51	37	81	67	30	33	117	80	23	676
	Gamma	58	46	53	51	37	81	67	30	33	117	80	23	676
	Alpha	10	-	1	9	15	15	17	2	3	16	9	-	97
Toxicology:	Mercury	5	4	-	-	5	7	6	-	1	1	3	5	37
	Polyphenyls	-	-	-	-	-	-	-	-	-	-	-	-	-
	Other toxics Pb	-	-	-	-	-	6	3	-	3	-	4	2	18
	Sound levels	1	-	5	4	-	-	-	1	-	-	-	-	11

1974	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Total
Recruiting and first examinations	9	19	23	16	33	39	27	8	22	27	5	7	235
Periodic examinations	228	157	176	196	179	113	162	111	205	210	217	161	2115
Examination on request	117	109	138	84	111	79	146	89	95	95	133	59	1255
Examination at home	5	4	4	7	6	7	2	-	4	3	4	4	50
Sight testing	42	47	41	34	36	35	33	49	53	48	58	39	515
Miniature-radiography	75	99	171	60	114	76	47	83	63	93	80	52	1013
Radiography	44	43	59	51	67	66	64	21	59	77	32	33	616
First aid cases	552	629	612	944	736	402	503	373	537	706	571	363	6928
Haematological laboratory	913	705	750	723	685	672	722	420	810	870	786	660	8716
Biochemical laboratory	1951	1630	1605	1446	1420	1304	1316	878	1557	669	1533	1609	17918
1975													
Recruiting and first examinations	15	13	15	16	21	16	24	12	20	30	16	6	204
Periodic examinations	188	155	182	221	163	214	212	151	212	197	166	146	2207
Examination on request	98	107	98	124	79	82	109	67	121	98	82	75	1140
Examination at home	6	4	4	4	6	5	3	-	9	7	7	4	59
Sight testing	45	41	-	27	28	26	50	22	32	56	42	37	406
Miniature-radiography	81	117	51	-	-	115	74	61	95	91	102	38	825
Radiography	60	59	46	65	47	52	60	34	69	77	59	43	671
First aid cases	398	522	557	610	425	571	438	364	546	863	594	438	6326
Haematological laboratory	831	687	729	861	635	993	906	657	834	950	734	598	9415
Biochemical laboratory	1566	1531	1503	1935	1374	1995	1624	1219	1743	2010	1828	1205	19533

Accidents at Work (Euratom Personnel)

1974	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Total
Contusions, simple strains, torn muscles	3	1	5	6	2	3	1	5	1	2	1	3	33
Wounds	4	7	7	6	6	3	11	4	2	5	4	3	62
Burns	6	-	-	1	3	2	1	2	-	-	3	1	19
Eye lesions	4	2	2	2	4	3	3	2	-	1	1	-	24
Fractures	-	-	-	-	1	-	1	-	-	1	-	-	3
Electric shocks	-	-	-	-	-	-	-	1	-	-	1	-	2
Total	17	10	14	15	16	11	17	14	3	9	10	7	143
1975													
Contusions, simple strains, torn muscles	2	4	3	6	2	-	6	2	1	3	2	-	31
Wounds	4	5	7	9	4	14	8	4	5	6	8	3	77
Burns	-	1	2	1	-	-	-	1	1	1	-	-	7
Eye lesions	2	-	4	-	1	1	2	3	2	2	1	-	18
Fractures	-	-	-	1	-	1	-	1	-	-	-	-	3
Electric shocks	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	8	10	16	17	7	16	16	11	9	12	11	3	136

Press and Public Relations

Maria-Piera Moretti

The main task of the Press and Public Relations Service is to inform the public at large about activities at the Ispra Nuclear Research Establishment and also to prepare and carry out meetings and congresses.

Essentially this entails sending out folders, leaflets and assorted printed matter, extracting cuttings from different newspapers, attending meetings and exhibitions and looking after visitors and participants and conferences.

Film shows play an important part in public relations activities at Ispra; for visiting groups, they round off introductory talks and also illustrate sections of the establishment which, for lack of time or opportunity, it would not be possible to visit.

In 1974/1975 the flow of visitors from the Community and other countries was regular and intense (especially groups of visitors from Italy and Germany).

Records for the years 1974 and 1975 show a total of 3,242 and 3,480 visitors with the following breakdown:

	1974	1975
Secondary schools/universities	832	1167
Political and scientific visitors, business	137	81
Firms, industries and organizations	260	214
Participants at meetings and scientific conferences	1407	1747
Individual visits	184	222
Representatives	12	49
Total	**3,242**	**3,480**

The Press and Public Relations Service, during the period 1874/1975 took care of the following (approximate figures) :

	1974	1975
Meetings	432	579
Film and Slide Projections	204	152
Recordings	94	124

Likewise:

2000 newspaper cuttings with dispatch of copies
4040 dispatches of weekly information sheets
2400 dispatches of monthly magazines.

The major meetings of the year 1975 were:

Second Ispra Nuclear Electronics Symposium
May 20-23, 1975

held at the Congress Hall of Stresa, with about 270 participants.

Fifth Symposium on Microdosimetry
September 22-26, 1975

held at the Grand Hôtel Majestic at Pallanza, with about 150 participants.

In October 1975 the Press and Public Relations Service created a weekly Press Review (150 copies) giving a survey of the main articles published in the most important European newspapers.

Moreover, a periodical calendar of the main meetings and visits held in the Joint Research Centre is being distributed to the different departments and services of the Centre.

During 1974/1975 close cooperation with the Cultural Committee of the establishment made it possible to carry out an interesting programme of concerts, exhibitions, lectures and discussions.

Security

E. Wennig

Security in a nuclear centre is a constant headache for the authorities responsible. Over the last few years the techniques of crime and the psychology underlying it, have taken on forms which impose considerable stresses on the facilities and manpower available for combating it.

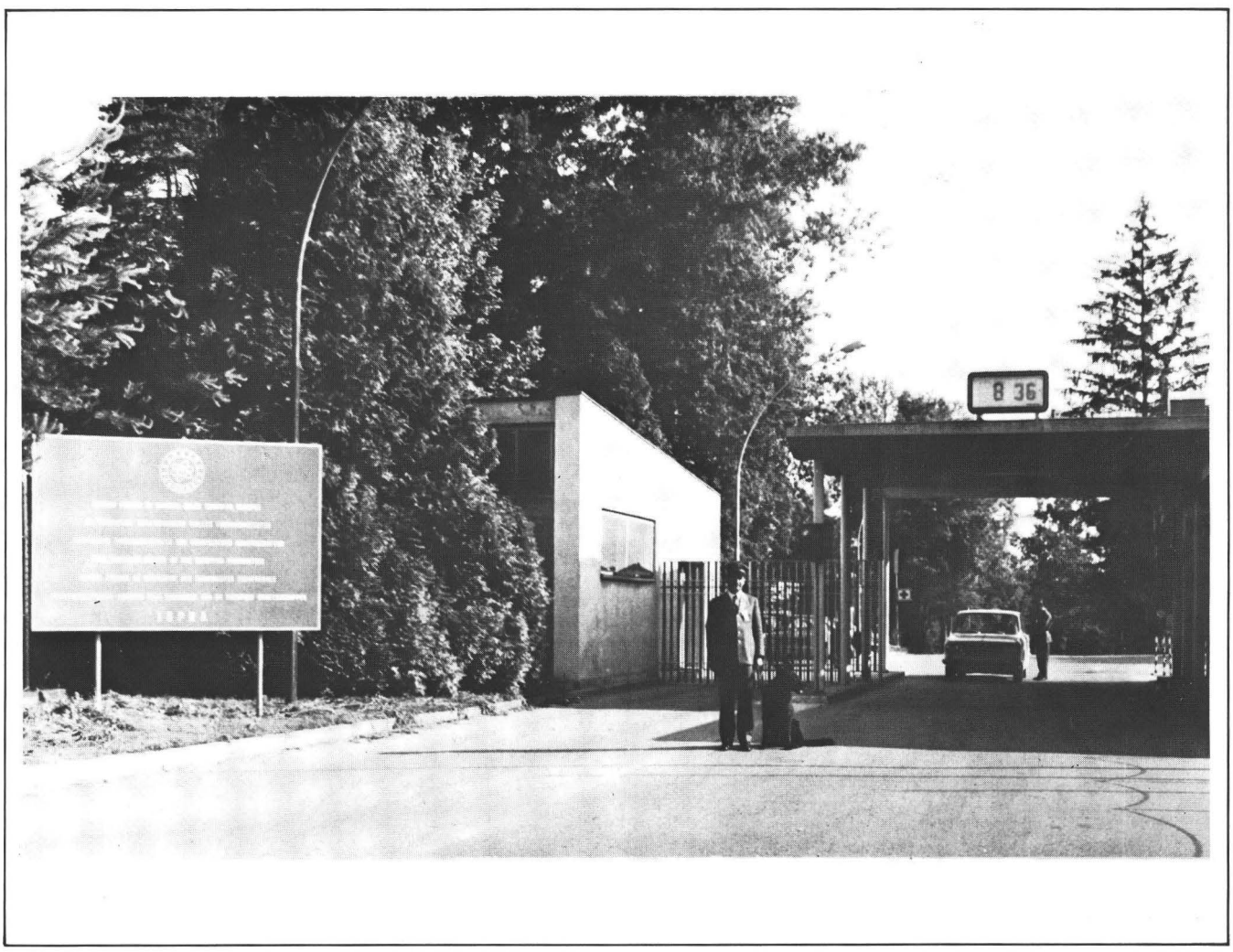
In 1974-1975 a start was made on conducting a complete overhaul of the security system at the Ispra JRC. The reappraisals of the security arrangements required by the Council Decision of 31 July 1958 and by the Commission Decision of 9 October 1969 and 19 November 1975 were carried out in close collaboration with the Security Office of the European Communities and the national authorities. The application of the Euratom regulations governing classified material was constantly verified by the JRC security service and, where necessary, special permits were granted authorizing access to such material.

The security of the buildings and site and the checking of visitors and staff at the main gate were the responsibility of the guards, whose resources were tested to the full by the presence of 1600-2000 persons in the Centre each day.

There is a special team for the surveillance of the ESSOR and ECO reactors, and the training of these guards was intensified during the period covered by the report.

In the overhaul of the physical security systems, absolute priority was given to the introduction of radio means of communications.

Modern alarms and monitoring devices were installed last year and now form an important part of the Centre's sophisticated security system.



LIST OF PUBLICATIONS

1974-1975

TECHNICAL EVALUATION IN SUPPORT OF THE ACTIVITIES OF THE COMMISSION

Reports

CONTI, F., GRAZIANI, G., VISEUR, R., ZANANTONI, C. – *Evaluation of Electrical Energy Production Patterns* – EUR 5336.e (1975)

CONTI, F., GRAZIANI, G. – *TOTEM, a computer program for the simulation of an electric power generation system* – EUR 5421.e (1975)

MARCHETTI, C., RINALDINI, C., SCHNEIDERS, A. – *Model of a strategy for Europe's energy supply based on methane as the prime energy carrier* – EUR 5140.e (1974)

NEU, H. – *A dynamic model for simulating future energy demand and supply in the European Communities. Scenarios for the year 2000 and beyond* – EUR 5399.e (1975)

Papers presented at scientific conferences

CONTI., F., GRAZIANI, G., MAINERI, M., RINALDINI, C., ZANANTONI, C. – *Effect of HTR's on power plant installation policies* – 1st European Nuclear Conference, Paris (France), April 21-25, 1975

GIACOMAZZI, G. – *Il Centro di Ispra del Centro Comune di Ricerca della Commissione delle Comunità Europee* – Riunione A.T.E.N.A. (Associazione di Tecnica Navale), Trieste (Italy), June 2-8, 1974

CONCEPTUAL STUDIES ON FUSION REACTORS

Papers presented at scientific conferences

CASINI, G. – *Thermomechanical and erosion effects in the first wall and blanket of power thermonuclear pulsed reactors* – Proceedings of the Symposium on Pulsed Fusion Reactors, Erice (Italy), September 9-20, 1974; pp 625-650; EUR 5307.e

CASINI, G., CUNIBERTI, R., CASALI-FARFALETTI, F. – *Preliminary design of a minimum size technical feasibility TOKAMAK fusion reactor* – First Topical Meeting of the Technology of Controlled Nuclear Fusion, San Diego/California (USA), April 16-18, 1974

CASINI, G., CUNIBERTI, R. – *Nuclear blanket and shielding problems in demonstration fusion reactors* – Proceedings of the First Topical Meeting on the Technology of Controlled Nuclear Fusion, San Diego (USA), April 16-18, 1974

BERTOLINI, E. et al. – *Design of a minimum size toroidal D-T experimental reactor (FINTOR) – Plasma physics and controlled nuclear fusion Research* – Fifth Conference Proceedings, Tokyo (Japan), November 11-15, 1974

The FINTOR Group – *Concentual design studies of an experimental power TOKAMAK reactor* – 8th Symposium on Fusion Technology, The Netherlands, 1974

RESEARCH UNDER CONTRACT

Papers presented in scientific periodicals

VERHEYDEN, L., KLEIN, K., OOMS, M., SCHINS, H. – *Caratteristiche delle guarnizioni MET-X ad alta temperatura (800 ÷ 1000°C)* – Vuoto, Scienza e Tecnologia, **8**, 54-66 (1975)

VERHEYDEN, L., SCHINS, H. – *Die Prüfung von Dichtungen bei höheren Temperaturen unter realen Bedingungen mittels des Prinzips des Wärmerohrs* – Kerntechnik, **16**, 23-24 (1974)

Reports

BORLOO, E., CRUTZEN, S. – *Ultrasonic signature* – EUR 5108.e (1974)

KLEY, W., MATTHES, W. – *The inverted statistical chopper facility for elastic and inelastic neutron scattering experiments* – EUR 5047.e (1974)

KLEY, W. – *Pulsed neutrons and their utilization* – EUR 5046.e (1974)

Papers presented at scientific conferences

VERHEYDEN, L., FELIX, F., NOLTES, G. – *Beitrag zum Diffusionsschweissen von Inconel 600* – 2nd International Conference on Welding in Nuclear Engineering, Düsseldorf (Germany), October 23-24, 1974. Deutscher Verlag für Schweisstechnik, DVS-Bericht 32

VERHEYDEN, L., KLEIN, K. – *Comportement du joint MET-X en Inconel 600 pendant refroidissement de la température ambiante jusqu'à 78°K.* – Journées de Technologie du Vide, Versailles (France), June 11-14, 1974.

NUCLEAR WASTE DISPOSAL

Papers presented in scientific periodicals

GIRARDI, F., BERTOZZI, G. – *I residui radioattivi: problema attuale* – Euro Spectra, **13,** 23-29 (1974)

TOUSSAINT, C.J., AVOGADRO, A. – *Concerning uranate formation in alkali nitrate melts* – Journal of Inorganic and Nuclear Chemistry, **36,** 781-784 (1974)

Reports

BERG, R., SWENNEN, R., BIRKHOFF, G., BONDAR, L., LEY, J., BUSCA, B. – *On the determination of the Pu-240 in solid waste containers by spontaneous fission neutron measurements. Application to reprocessing plant waste* – EUR 5158.e (1974)

DITTERICH, K., SCHNEIDER, J. – *Systems analysis as a tool for optimal process strategy* – EUR 5372.e (1975)

GIRARDI, F., BERTOZZI, G. – *Long-term alpha-hazard of high activity waste from nuclear fuel reprocessing* – EUR 5214.e (1974)

Papers presented at scientific conferences

BERTOZZI, G., GIRARDI, F., MOUSTY, F. – *Removal of long lived alpha emitters from aqueous high level waste* – 4th International Transplutonium Element Symposium, Baden-Baden (Germany), September 12-18, 1975

BIRKHOFF, G. – *On the determination of plutonium in solid waste containers by spontaneous fission neutron measurements* – Proceedings of the Seminar on the Management of Pu Contaminated Solid Waste, Marcoule (France), October 14-16, 1974

BRAUN, H.W.M., DITTERICH, K., SCHNEIDER, J. – *Zur Optimierung des Managements radioaktiver Abfälle in der Europäischen Gemeinschaft mit Hilfe systemanalytischer Methoden* – Jahrestagung des Fachverbandes für Strahlenschutz e.V., Helgoland (Germany), September 23-28, 1974

HAGE, W., SCHMIDT, E. – *Concepts for the nuclear transmutation of radioactive waste from fission reactors at present under discussion* – Joint Euratom Nuclear Data and Reactor Physics Community, Risø (Denmark)

MATERIALS SCIENCE AND BASIC RESEARCH ON MATERIALS

Papers presented in scientific periodicals

BASSI, A., MATERA, R., PIATTI, G., WENGER, D. – *Structure et caractéristiques de l'alliage eutectique Ni-Ni$_3$Ta obtenu par solidification unidirectionnelle* – Mémoires Scientifiques Revue Métallurgie, **2,** 171-181 (1975)

BETTINETTI, G.-F., FACCHETTI, S. – *3-Aryl-2-Isoxazolines: electron-impact fragmentation and substituent effects* – Organic Mass Spectrometry, **9,** 753-762 (1974)

BIGNOLI, G., RUEDL, E., MERLETTI, G. – *Microanalisi a raggi X mediante il microscopio a scansione di ossidi cresciuti su leghe di Ni-Mo* – Journal Submicron, Cytol, **6,** 135 (1974)

BOEUF, A., GOBER, G., RUSTICHELLI, F. – *A versatile neutron diffractometer* – Nuclear Instruments and Methods, **124,** 533-540 (1975)

BOEUF, A., RUSTICHELLI, F. – *Some neutron diffraction on curved silicon crystals* – Acta Crystallographica, **A30,** 798-805 (1974)

BONI, M., CAMAGNI, P., GIANI, E. – *Enhancement of F-centre colouration during plastic deformation of alkali halides* – Journal of Physics and Chemistry of Solids, **36,** 883-891 (1975)

CAPPELLANI, F., RESTELLI, G., SPIONI, L. – *Isothermal anneal of arsenic-implanted silicon* – J. Physics C: Solid State Physics, **7,** 3, L50-L53 (1974)

CARLILE, C.J., KREBS, K. – *Quasielastic neutron scattering and orientational motions in liquid crystals* – Molecular Crystals and Liquid Crystals, **29,** 43-56 (1974)

DIANA, E., GALGANI, L., GIOGILLI, A., SCOTTI, A. – *On the direct construction of formal integrals of a hamiltonian system near an equilibrium point* – Bollettino della Unione Matematica Italiana, **4,** 11, 84-89 (1975)

GUARDINI, S. – Relative conversion ratio measurements in D_2O moderated, U and UO_2 fuelled lattices – Energia Nucleare, **22,** 7, 374-381 (1975)

HELCKE, G., FANTECHI, R. – *Electron spin resonance and CNDO/2 study of the radicals produced during fast electron irradiation of substances containing nitrogen* – Journal of the Chemical Society, Faraday Transactions II, **70,** 1-8 (1974)

HOTZ, W., RUEDL, E., SCHILLER, P. – *Observation of processes of superplasticity with the scanning electron microscope* – Journal of Materials Science, **10,** 2003-2006 (1975)

HUEZ, M., RESTELLI, G., MANARA, A. – *On the anodic oxide grown on silicon carbide* – Thin Solid Films, **23**, S33-S-36 (1974)

KIESEWETTER, N. – *Acoustic emission from moving dislocations* – Metallurgica, **8**, 249-252 (1974)

KOEKSAL, F., KRUEGER, G.J. – *Electron spin relaxation of (diphenyl)⁻ in dimethoxyethane* – Zeitschrift für Naturforschung, **30A**, 883-890 (1975)

KRUEGER, G.J., SPIESECKE, H., VAN STEENWINKEL, R. – *Nuclear magnetic relaxation and diffusion measurements in p-dodecanoylbenzylidene-p'-aminoazobenzene* – Journal de Physique, **36**, C1-91-C1-92 (1975)

KRUEGER, G.J., SPIESECKE, H., WEISS, R. – *A simple spin echo measurement of the anisotropy of the self-diffusion coefficient in a smectic a and b type liquid crystal* – Physics Letters, **51A**, 295-296 (1975)

MAZKEDIAN, S., MELONE, S., RUSTICHELLI, F. – *On the diffraction by cholesteric liquid crystals with a pitch gradient* – Journal de Physique, Colloque C-1, suppl. n°3, tome 36, 283-287 (1975)

PELLEGRINI, G., PIATTI, G. – *Calcium: a possible substitute for geochemically scare metals* – Euro Spectra, **13**, 112-120 (1974)

PIATTI, G., DEJACE, J., FOSSATI, C., MATERA, R. – *The growth of the Ni-Ta-Cr-Mn system* – Journal of Materials Sciences, **9**, 1917-1925 (1974)

PROVENZANO, V. SCHILLER, P., SCHNEIDERS, A. – *Internal friction study of zirconium alloyed with hydrogen and deuterium* – Journal of Nuclear Materials, **52**, 75-84 (1974)

RESTELLI, G., OSTIDICH, A., MANARA, A. – *Anodic oxidation of silicon carbide* – Thin Solid Films, **23**, 23-29 (1974)

RIEF, H., HARTMAN, J. – *The effectivity of hydrogeneous moderators in pulsed neutron sources* – Annals of Nuclear Energy, **2**, 521-539 (1975)

RUEDL, E. – *Phase transformations in the alloy hastelloy B* – Materials Research Bulletin, **10**, 1267-1272 (1975)

RUEDL, E., MERLETTI, L., PIZZINI, S. – *Study of the high-temperature oxidation of NiMo alloys by means of electron microscopic techniques and thermogravimetry* – Journal Submicron, Cytol, **6**, 137 (1974)

RUEDL, E., STAROSTE, E. – *Transmission electron microscopy of cavities by means of focalized or defocalized images* – Journal Submicron, Cytol, **6**, 140 (1974)

RUSTICHELLI, F. – *On the deviation from the Bragg law and the widths of diffraction patterns in perfect crystals* – Philosophical Magazine, **31**, 1 (1975)

SCHERFF, H.L., SPRINGER, H. – *Redetermination of the carbon-rich phase boundary of uranium monocarbide* – Journal of Nuclear Materials, **56**, 153-160 (1975)

SCHILLER, P., NIJMAN, H. – *The orientation of the low temperature relaxation peak in NbOH* – Physica Status Solidi, **31**, 77-79 (1975)

SCHUELE, W. – *Self-interstitials in aluminium* – Journal of Nuclear Materials, **56**, 368-370 (1975)

SCHUELE, W., CRESTONI, G. – *Short range order in gold-silver alloys* – Zeitschrift für Metallkunde, **66**, 728-736 (1975)

SCHUELE, W., SPINDLER, P., LANG, E. – *Entmischung in Kupfer-Nickel-Legierungen durch thermische Behandlung und durch Neutronenbestrahlung* – Metallkunde, **66**, 50-56 (1975)

VAN DER VOORT, E. – *Anion vacancy migration in CaF_2 lattices and in monoclinic ZrO_2* – Journal of Physics C: Solid State Physics, **7**, C395-C399 (1974)

VAN STEENWINKEL, R. – *Nuclear relaxation and slow diffusive motions in CaF_2 and NaF* – Zeitschrift für Naturforschung, **29A**, 278-281 (1974)

VESENTINI, L., PELLEGRINI, G., SARACCO, G., ZUBANI, I. – *Thermally induced structural modifications in pyrolytic carbons and their relationship with the deposition temperature* – Journal of Nuclear Materials, **52**, 157-166 (1974)

Reports

BETTENDROFFER, E., EDER, J. – *A digital system for speed and phase control of phased neutron chopper arrays* – EUR 5112.e (1974)

EDER, J. – *MOSIF – A data acquisition system for the study of solids motion in fluidized beds* – EUR 5115.e (1974)

EDER, J., BRACK, H. – *Interface zur Steuerung einer Multichopperanlage* – EUR 5121.d (1974)

FORTE, M. – *Neutron spin precession in polarized nuclear targets* – EUR 5054.e (1974)

MAIER, K., SCHUELE, W. – *Niederenergetische Ionenstrahl-Kathodenzerstäubung als allgemein anwendbares Abtrageverfahren zur Messung von Festkörperdiffusion* – EUR 5234.d (1974)

REITER, R.W., CAMPOSILVAN, J. – *Desorption spectra and adsorption states in the Mo-N_2 system* – EUR 5404.e (1975)

Papers presented at scientific conferences

ALBERTINI, C., MONTAGNANI, M. – *Testing techniques based on the split Hopkins bar* – Conference on the Mechanical Properties of Materials at High Rates of Strain, Oxford (GB), April 2-4, 1974 Institute of Physics Conference Series, 21, 22-32 (1974)

BASSI, A., CAMONA, G., WENGER, D., BOERMAN, D., MATERA, R., PIATTI, G. – *Relazioni tra struttura e proprietà meccaniche nell'eutettico Ni-Ni_3Ta solidificato unidirezionalmente* – XVI Convegno Nazionale AIM, Pisa (Italy), April 26-28, 1974

BOERMAN, D., MATERA, E., PELLEGRINI, G., PIATTI, G. – *Morphology and mechanical behaviour of aligned dendritic composites* – Second International Symposium on Composite Metallic Materials, Smolenics (Czechoslovakia), October 29-31, 1975

BOEUF, A., RUSTICHELLI, F. – *Some neutron dynamical diffraction experiments on curved silicon crystals* – Tenth International Congress of Crystallography, Amsterdam (The Netherlands), August 7-17, 1975

BOEUF, A., RUSTICHELLI, F., LAGOMARSINO, S. – *White beam neutron topography* – Tenth International Congress of Crystallography, Amsterdam (The Netherlands), August 7-17, 1975

BOHDANSKI, J., GIUGE, M. – *Influence of the oxygen on the workfunction of tungsten and its variations with the evaporation rate* – 1975 Thermionic Conversion Specialists Meeting, Eindhoven (The Netherlands), September 1-3, 1975

BOHDANSKI, J., ROTZ, K. – *Collector heat dissipation in a variable spacing diode* – 1975 Thermionic Conversion Specialists Meeting, Eindhoven (The Netherlands), September 1-3, 1975

BOHDANSKI, J., ROTH, J., POSCHENRIEDER, W.P. – *The trapping of hydrogen ions in zirconium for ion energies between 0.3 and 6 keV* – The Application of Ion Beams to Materials, Warwick (GB), September 8-12, 1975

BURGEAT, J., PRIMOT, J., RUSTICHELLI, F. – *Observation by dynamical diffraction of an anisotropic effect in the imperfections due to oxidation of perfect Si crystals* – International Crystallography Conference, Melburne (Australia), August 19-23, 1974

CAPPELLANI, F., HUEZ, M., RESTELLI, G. – *Meccanismo di attivazione elettrica di arsenico impiantato in silicio* – Convegno C.N.R., Bologna (Italy), June 25-26, 1974

DIANA, E., SCOTTI, A. – *Some numerical computations related to Kolmogorov entropy* – International Conference on Statistical Physics, Budapest (Hungary), August 25-29, 1975

DIANA, E., SCOTTI, E. – *Studies on the onset of stochasticity in a one-dimensional non-linear classical system* – International Conference on Statistical Physics, Budapest (Hungary), August 25-29, 1975

DIERCKX, R., SANGIUSTI, V., McCRAKEN, V., SCHNEIDER, W. – *Unfolding codes for neutron spectra evaluation possibilities and limitations* – Intercomparison of Neutron Spectra Evaluation Methods using Activation Detectors, Petten (The Netherlands), September 22-26, 1975

FACCHETTI, S., BETTINETTI, G. – *Retrocicloaddizioni e trasposizioni feniliche indotte da reazioni ione-molecola in alcuni compositi eterociclici* – Terzo Convegno Spettrometria di Massa, Roma (Italy), April 22-24, 1974 – Annali di Chimica, 64, 131-138 (1974)

FREUND, A., LUCARINI, G., MAZKEDIAN, S., RUSTICHELLI, F. – *Theoretical and experimental studies of the deviation from Bragg's law in X-ray back-scattering experiments* – International Crystallography Conference, Melbourne (Australia), August 19-23, 1974

HAUPT, J. – *Thermally induced dipolar polarization in samples of γ-picoline containing impurities of helium and benzene* – 18th Ampere Congress, Nottingham (UK), September 9-14, 1974

HERVET, H., LAGOMARSINO, S., RUSTICHELLI, F. – *Orientational order in smectic phases of TBBA liquid crystals by neutron diffraction* – Tenth International Congress of Crystallography, Amsterdam (The Netherlands), August 7-17, 1975

HUEZ, M., MANARA, A., RESTELLI, G. – *Ossidazione anodica del carburo di silicio* – Convegno C.N.R., Bologna (Italy), June 25-26, 1974

KLEY, W. – *Basic design criteria for a continuous medium-power (20-30 MW), low cost high flux research reactor and its associate equipment for scientific and technical research* – 1st Scientific Conference of the Iraqi A.E.C., Bagdad (Iraq), April 7-11, 1975

KRUEGER, G.J. – *Kernresonanzuntersuchungen der Wasserstoffdiffusion in Vanadiumhydrid* – Institut für Physik und Chemie der Westfälischen Wilhelms-Universität, Münster/Westfalen (Germany), January 30, 1975

KRUEGER, G.J., SPIESECKE, H., VAN STEENWINKEL, R. – *Nuclear magnetic relaxation and self diffusion in some liquid crystals showing smectic polymorphism* – European Conference on Thermotropic Smectics and their Applications, Les Arcs (France), December 15-18, 1975

KRUEGER, G.J., WEISS, R. – *Diffusion of hydrogen in vanadium hydride as studied by NMR techniques* – Proceedings of the 18th Ampere Congress, Nottingham (GB), September 9-14, 1974, pp 339-340

LUCARINI, G., MAZKEDIAN, S., RUSTICHELLI, F. – *On the deviation from the Bragg-law in the symmetric Bragg case diffraction in X-rays and neutrons by perfect crystals* – Tenth International Congress of Crystallography, Amsterdam (The Netherlands), August 7-15, 1975

MARACCI, G., MERLINI, A., PACE, S. – *Diffuse Mössbauer scattering applied to the formation of omega phase in Zr-20%Nb alloy* – International Conference on the Application of the Mössbauer Effect, Bendor (France), September 2-6, 1974

MAZKEDIAN, S., MELONE, S., RUSTICHELLI, F. – *Circular dichroism and rotatory dispersion in cholesteric liquid crystals with a pitch gradient* – Tenth International Congress of Crystallography, Amsterdam (The Netherlands), August 7-15, 1975

MEISTER, H. – *Evidence of phase mixing in the critical region of the ferroelectric phase transition in deuterated KDP* – Riunione Scientifica Annuale 1975 del G.N.S.M., Catania (Italy), May 28-30, 1975

OLEOWNIK, G., SCHUELE, W. – *Vacancies, interstitials, and crowd ions in copper gold alloys* – International Conference on Fundamental Aspects of Radiation Damage in Metals, Gatlinburg/Tennessee (USA), October 5-10, 1975

PIATTI, G. – *Preparation of new multiphase composites* – International School of Physics, Varenna (Italy), July 8-20, 1974

PIATTI, G. – *Attività di ricerca sui compositi metallici fibrosi* – Primo Convegno Nazionale Materiali Compositi, Sorrento (Italy), October 23-24, 1975

PIATTI, G., PELLEGRINI, G., TRIPPODO, R. – *Structure and properties of the Al-Al_4Ca eutectic* – 6th International Light Metals Conference, Loeben (Austria), June 16-20, 1975

SCHILLER, P. – *Hydrogen in metals as observed by internal friction and magnetic disaccommodation* – Second European Conference on Internal Friction, Roma (Italy), September 3-5, 1975

SCHILLER, P., SCHNEIDERS, A., NIJMAN, H. – *Internal friction as a tool to study impurities: demonstrated for the case niobium with hydrogen, oxygen* – International School of Physics "E. Fermi", Varenna (Italy), July 10-12, 1974

SCHUELE, W., LESSMANN, E. – *Self interstitials in nickel* – International Conference on Fundamental Aspects of Radiation Damage in Metals, Gatlinburg /Tennessee (USA), October 5-10, 1975

SCHUELE, W., MAIER, K., LESSMANN, E. – *Self diffusion coefficients in copper and nickel* – International Conference on Fundamental Aspects of Radiation Damage in Metals, Gatlinburg/Tennessee (USA), October 5-10, 1975

Papers related to the work done at the Petten Establishment during 1974

Papers presented in scientific periodicals

BRESSERS, R., CRETEN, R., VAN HOLSBEKE, G. – *Preparation and characterization of high-purity vanadium by EBFZM* – J. Less-Common Metals, **39**, 7-16 (1975)

CAMBINI, M., SERNEELS, R., GEVERS, R. – *Ordering of hydrogen in β-vanadium hydride near to V_2H* -Phys. Stat. Sol. (a) **21**, K 57 (1974)

CAMBINI, M. – *Ordering of interstitial nitrogen and oxygen in vanadium near to V_8N and V_8O* - Mat. Res. Bull., **9**, 1469 (1974)

GUTTMANN, V. – *Einfluss von Verformungsgrad und Korngrösse auf den Ort der Keimbildung bei der Primärkristallisation von Vanadium* – J. of the Less-Common Metals, **38**, 111-118 (1974)

Reports

LANG, E. – *Point defects in vanadium – The recovery behaviour upon coldwork* – EUR 5145.e (MF) (1974)

LANG, E., CANETOLI, S., D'AMICO, S., SARACCO, C. – *Studio del comportamento del vanadio nella deformazione a bassa temperatura e nel successivo recupero* – EUR 5156.i (MF) (1974)

LANG, E. – *Ueber Messungen der gespeicherten Energie and kaltverformten polykristallinen Cu-Proben* – EUR 5106.d (1974)

NON-ELECTRICAL APPLICATION OF NUCLEAR ENERGY HYDROGEN PRODUCTION FROM WATER

Papers presented in scientific periodicals

BARBI, G.B., MONTI, P. – *The voltammetric behaviour of Hg^{++} at solid microelectrodes* – Analusis, **2**, 729-733 (1973-1974)

BEGHI, G. – *Produzione e utilizzazione dell'idrogeno con nuove tecnologie* – La Termotecnica, **29**, 3, 179-194 (1975)

BEGHI, G. – *Prospettive dell'idrogeno nei sistemi energetici futuri* – L'Elettrotecnica, **62**, 8, 653-666 (1975)

BEGHI, G. – *Produzione e utilizzazione dell'idrogeno con nuove tecnologie* – Gas, **3**, 71-91 (1975)

BEGHI, G. – *Hydrogen production and high temperature reactors* – Energia Nucleare, **22**, 69-77 (1975)

BEGHI, G., DEJACE, J., MASSARO, C., CIBORRA, B. – *Economics of pipeline transport for hydrogen and oxygen* – Entropie, **59**, 37-44 (1974)

DE BENI, G. – *Thermochemical processes for hydrogen production* – Energia Nucleare, **22**, 141-148 (1975)

MARCHETTI, C. – *The use of hydrogen as an energy carrier* – Superconducting Machines and Devices, **8**, 549-562 (1974)

RUEDL, E., PIZZINI, E., MERLETTI, S. – *Metal-slag-gas reactions and processes* – The Electrochemical Society, 448-463 (1975)

Reports

BEGHI, G., editor, *Hydrogen production from water using nuclear heat – Annual Progress Report No. 3,* EUR 5059.e (1974)

BEGHI, G., DEJACE, J., CIBORRA, B., MASSARO, C. – *Hydrogen, oxygen and natural gas by pipelines: comparative transport costs* – EUR 5103.e (1974)

GAUTSCH, O., HODAPP, G. – *The specific heats of $CaBr_2$ solutions* – EUR 5379.e (1975)

GAUTSCH, O., HODAPP, G. – *Some thermodynamic data on $CaBr_2$ solutions* – EUR 5444.e (1975)

Papers presented at scientific conferences

BEGHI, G. – *L'economia dell'idrogeno* – Corso sull'Ingegneria e Economia del Sistema Energetico, CESNEF, Politecnico di Milano (Italy), February 14, 1974

BEGHI, G. – *Produzione e utilizzazione dell'idrogeno con nuove tecnologie* – Convegno Evoluzione ed Innovazione delle Fonti di Energia, Milano (Italy), May 20-21, 1974; La Termotecnica, **29**, 3, 179-194 (1975)

BEGHI, G. – *Perspectives of thermochemical processes for water decomposition in a future hydrogen system* – Würenlingen (Switzerland), July 10, 1975

BEGHI, G. – *L'idrogeno come vettore d'energia: prospettive di un contributo alla soluzione dei problemi energetici* – Meeting Accademia Patavina, Padova (Italy), November 16, 1974

BEGHI, G. – *Prospettive dell'idrogeno nei sistemi energetici futuri* – 13th Nuclear Energy Conference: Nuclear Energy Perspective, Milan (Italy), December 12-24, 1974

BEGHI, G., BROGGI, A., DE BENI, G. – *Thermochemical water splitting as a method for hydrogen production* – Proceedings of the BNES Conference: The High Temperature Reactor and Process Applications, London (GB), November 26-28, 1974

BEGHI, G., DEJACE, J., MASSARO, C., CIBORRA, B. – *Economics of pipeline transport for hydrogen and oxygen* – The Hydrogen Economy Miami Energy Conference, Miami/Florida (USA), March 18-20, 1974; Hydrogen Energy, part A, 5, 45, 560 (1974)

BEGHI, G., DE BENI, G. – *Processi termochimici di decomposizione dell'acqua: prospettive di un nuovo metodo di produzione di idrogeno con calore nucleare* – 26e Giornate della Chimica, Milan (Italy), April 21-22, 1975

BROGGI, A., BEGHI, G. – *Method of evaluation of nuclear thermochemical processes for water decomposition* – European Nuclear Conference, Paris (France), April 21-25, 1975

COEN, F., IMARISIO, G. – *Corrosion problems in the thermochemical hydrogen production from water* – 7th Meeting of the European Working Group "Nuclear Corrosion", Ispra (Italy)

DE BENI, G. – *L'idrogeno come vettore di energia* – Riunione Periodica del Rotary Club, Bergamo (Italy), January 14, 1974

DE BENI, G. – *Considerations on iron-chlorine-oxygen reactions in relation to thermochemical water splitting* – THEME Conference, Miami/Florida (USA), March 18-20 (1974); Proceedings Hydrogen Energy, Part A, 471-482

DE BENI, G., BEGHI, G. – *Thermochemical decomposition of water as a method for hydrogen production by using nuclear heat* – Meeting of the Working Group on Nuclear Heat Utilisation for Industrial Applications and District Heating, IAEA, Vienna (Austria), September 2-6, 1974

DE BENI, G. – *Considerazioni termodinamiche e cicli termochimici per la decomposizione dell'acqua* – Meeting Accademia Patavina, Padova (Italy), November 16, 1974

DE BENI, G. – *Procedimenti termochimici per la produzione di idrogeno da calore nucleare* – 13th Nuclear Energy Conference: Nuclear Energy in Perspective, Milan (Italy), December 12-14, 1974

DE BENI, G. – *Hydrogen production by water splitting: closed cycles of chemical reactions* – European Nuclear Conference, Paris (France), April 21-25, 1975

HAEFELE, W., DE BENI, G. – *Other applications of nuclear energy* – 1st European Nuclear Conference, Paris (France), April 21-25, 1975

VAN VELZEN, D. – *Gas and solids movement in spouted beds* – Chemical Engineering Congress, CHISA, Prague (Czechoslovakia), August 25-29, 1975

REACTOR SAFETY PROGRAMME

Papers presented in scientific periodicals

BERNARD, J., HENRY, B. – *Evaluation of the degree of structural interaction between longitudinally slitted tubes and patches in cyclic and monotonic pressure tests* – International Journal of Fracture Mechanics, **10**, 272-275 (1974)

COLOMBO, A.G., REINA, G., VOLTA, G. – *Extreme value characteristics of distributions of cumulative processes* – IEEE Transactions on Reliability, **23**, 3, 179-186 (1974)

DONEA, J., GIULIANI, S., PHILIPPE, A. – *Finite elements in the solution of electromagnetic induction problems* – International Journal for Numerical Methods in Engineering, **8**, 359-367 (1974)

DONEA, J., GIULIANI, S. – *Finite element analysis of steady-state non-linear heat transfer* – Nuclear Engineering and Design, **30**, 205-213 (1974)

EIFLER, W., NIJSING, R. – *Convection of coolant temperature perturbations in fast reactor fuel bundles* – Atomwirtschaft – Atomtechnik, **19**, 495-497 (1974)

W. EIFLER, NIJSING, R. – *Das Abklingen von Störungen des Geschwindigkeitsfeldes in Stabbündel-Brennelementen* – Atomwirtschaft - Atomtechnik, **20,** 4, 177-179 (1975)

LAUER, H. – *Numerische Lösungen der inversen eindimensionalen instationären Wärmeleistungsgleichung und ihre Anwendungen auf transiente Siedeprobleme* – Atomkernenergie, **24,** 3, 215 (1974)

NIJSING, R., EIFLER, W. – *A computation method for the steady state thermohydraulic analysis of fuel rod bundles with single phase cooling* – Nuclear Engineering and Design, **30,** 145-185 (1974)

NIJSING, R., EIFLER, W. – *The hybrid method, a new accurate computation method for transient temperature distributions in fuel rods* – Nuclear Engineering and Design, **32,** 208-220 (1975)

NIJSING, R., EIFLER, W. – *Lateral turbulent diffusion for longitudinal flow in a rectangular channel* – Nuclear Engineering and Design, **32,** 221-238 (1975)

OHLMER, E., SCHWALM, D. – *The use of the amplitude distribution function of temperature noise for malfunction detection in a simulated reactor subassembly* – Atomkernenergie, **25,** 4, 281-284 (1975)

SCHINS, H.E.J. – *Incipient and nucleate boiling of sodium* – Atomkernenergie, **24,** 243-246 (1974)

SCHINS, H.E.J. – *Contribution to the boiling curve of sodium* – Atomkernenergie, **26,** 1, 48-52 (1975)

SPILLER, K.H., GRASS, G., DROSTE, D. – *Contribution to the superheat of sodium at the incipiency of boiling* – Atomkernenergie, **26,** 2, 93-98 (1975)

Reports

BERNARD, J., HENRY, B. – *Etude expérimentale de l'effet de la courbure sur la valeur du facteur d'intensité de contrainte dans les coques cylindriques* – EUR 5137.f (1974)

DE WINDT, P., REYNEN, J. – *EURCYL, a program to generate finite element meshes for pressure vessel nozzles* – EUR 5257.e (1974)

DE WINDT, P., REYNEN, J. – *EURCRACK, a finite element mesh generation program for cracked pressure vessel nozzles* – EUR 5446.e (1975)

DONEA, J., GIULIANI, S. – *Code TAFSET numerical solution to transient heat-conduction problems using finite elements in space and time* – EUR 5049.e (1974)

FORTI, G. – *The computer program MATTEO for subchannel analysis of BWR rod bundles in steady state and transient* – EUR 5148.e (1974)

FRIZ, G., RIEBOLD, W. – *Pressure history during flashing caused by a sudden expansion* – EUR 5039.e (1974)

GARRIBA, S., REINA, G., VOLTA, G. – *Repair processes: fundamentals and computation* – EUR 5232.e (1974)

HAGE, W., HETTINGER, H., HOHMANN, H., TINAGLI, F., TOSELLI, F., SCHNEIDER, H. – *Coolant void experiments in ECO in 19-rod U and U-Pu fuel clusters* – EUR 5044.e (1974)

HERZBERGER, P., HUFSCHMIDT, W. – *Bestimmung des Dampfgehaltes und der Strömungsform eines Zweiphasengemisches in konzentrischen Ringspalten* – EUR 5077.d (1974)

HERZBERGER, P., HUFSCHMIDT, W., WIND, F. – *Die Verwendung von Gamma- oder Röntgenstrahlen zur Messung des Dampfgehaltes in Zweiphasen-Strömungen* – EUR 5415.d (1975)

LANZA, F., BURG, H. – *Valutazione statistica delle proprietà meccaniche delle grafiti industriali: Parte 1 – Studi sperimentali delle distribuzioni della resistenza meccanica* – EUR 5382.i (1975)

LARSEN, L. – *A sensitivity and assessment study of THETA-1B, a computer program for nuclear reactor code thermal analysis* – EUR 5448.e (1975)

LAUER, H. – *Numerische Lösungen der inversen eindimensionalen instationären Wärmeleitungsgleichung und ihre Anwendungen auf transiente Siedeprobleme* – EUR 5348.d (1975)

MOL, M.J., KLEIH, R. – *LAM-16, a 16 channel low-level amplifier and multiplexer* – EUR 5378.e (1975)

NAVARRE, J.Ph., MOUREAU, J.Cl., GIOT, M. – *Analyse cinématique et dynamique du comportement de bulles d'argon dans des canaux de NaK cylindriques et verticaux* – EUR 5069.f (1974)

OHLMER, E. – *Sonden für die Messung von Temperaturschwankungen in Strömungen* – EUR 5314.d (1975)

PONTI, C., VAN HEUSDEN, R. – *SABINE-3, an improved version of the shielding code SABINE* – EUR 5159.e (1974)

RANDLES, J. – *Second Specialist Meeting on Sodium/Fuel Interaction in Fast Reactors* – EUR 5309.e (1975)

RENARD, A., EVRARD, G., BRUZZI, G., DAL BEN, S., FORTI, G., VINCENTI, E. – *The code CARMEN-COSTANZA for the dynamics of sodium cooled fast breeder reactors* – EUR 5144.e

SCHWALM, D. – *Suggestions for the interpretation of temperature noise measurements in a heated linear bundle in a water loop* – EUR 5340.e (1975)

Papers presented at scientific conferences

ALBERTINI, C., BENUZZI, A., DONEA, J., FASOLI-STELLA, P., FINZI, S., HOLTBECKER, H. – *Ispra's contribution to an analysis of the consequences of hypothetical explosive accidents in fast reactors* – ENS-ANS First European Conference, Paris (France), April 21-25, 1975

ALBERTINI, C., CENERINI, R., CURIONI, S., MONTAGNANI, M. – *Temperature effects on dynamic straining of austenitic steels – Application to nuclear reactor safety* – Thermoplasticity Euromech 53, Warsaw (Poland), September 16-19, 1974

ALBERTINI, C., MONTAGNANI, M. – *Waves propagation effects on dynamic loading* – International Seminar on Extreme Load Conditions and Limit Analysis, Procedures for Structural Reactor Safeguards and Containment Structures, Berlin (Germany), September 8-11, 1975

BALESTRIERI, S., COLOMBO, A.G., LUISI, T., BOGANI, G., VERRE, A., BOTTELLI, B. – *Use of standard reliability levels in design and safety assessment of an in-pile loop* – Proceedings of the IAEA International Symposium on Reliability of Nuclear Power Plants, Innsbruck (Austria), April 1975

BENUZZI, A., FASOLI-STELLA, P., HOLTBECKER, H., VERZELETTI, G. – *Results of parametric REXCO H (Release 2) calculations and their comparison with experimental data* – Third International Conference on Structural Mechanics in Reactor Technology, London (GB), September 1-5, 1975

BERNARD, J. – *Fatigue crack growth in AISI 304 tubes under mixed mode loading conditions* – Third International Conference on Structural Mechanics in Reactor Technology, London (GB), September 1-5, 1975

CASINI, G., CUNIBERTI, R. – *Nuclear blanket and shielding problems in demonstration reactors* – First Topical Meeting of the Technology of Controlled Nuclear Fusion, San Diego/California (USA), April 16-18, 1974

COLOMBO, A.G., VOLTA, G. – *Multistep reliability analysis and optimization of complex systems* – Specialist Meeting on the "Development and Application of Reliability Techniques to Nuclear Plants", Liverpool (UK), April 8-10, 1974

COLOMBO, A.G., VOLTA, G. – *Logic-probabilistic approaches for nuclear safety assessment* – Conference on Reliability and Fault-Tree Analysis, Berkeley/California (USA), September 3-7, 1974

COLOMBO, A.G., LUISI, T., VOLTA, G., PALAMIDESSI – *Reliability analysis of electrical power supply systems* – Colloque International sur la Fiabilité des Centrales Nucléaires, Innsbruck (Austria), April 14-18, 1975

COUDERT, C., VOLTA, G., AMESZ, J. – *Probabilistic approach of PWR safety – Application to over-pressure protection* – First European Nuclear Conference, Paris (France), April 21-25, 1975.

DONEA, J., GIULIANI, S. – *EURDYN, a finite-element code for dynamic analysis of large displacements, small strain problems with material non-linearities* – Third International Conference on Structural Mechanics in Reactor Technology, London (GB), September 1-5, 1975

DONEA, J., GIULIANI, S., HALLEUX, J.P. – *Prediction of the non-linear dynamic response of structural components using finite elements* – ELCALAP Seminar, Berlin (Germany), September 8-11, 1975

EGLEME, M., STIEVENART, M., HOLTBECKER, H. – *Study of nuclear accidents by chemical simulation experiments* – ANS Topical Meeting on Fast Reactor Safety, Los Angeles/California (USA), April 2-4, 1974

EIFLER, W. – *Geschwindigkeitsfelder und Druckverlustbeiwerte in Bündelgeometrien* – Seminar der KTG-Fachgruppe "Thermo- und Fluiddynamik", Bensberg (Germany), March 11, 1975

EIFLER, W., NIJSING, R. – *Ein Modell zur Berechnung der Amplitudenverteilung fluktuierender Temperaturfelder und seine Anwendung auf ein Stabbündel-Brennelement des Typs SNR* – Reaktortagung 1976, Düsseldorf (Germany) March 30 – April 2, 1975

EIFLER, W., NIJSING, R. – *Das Abklingen von Störungen des Geschwindigkeitsfelds in Stabbündelbrennelementen* – Reaktortagung des Deutschen Atomforums, KTG, Nürnberg (Germany), April 8-11, 1975

FORTI, G. – *NICKY, a computer program for the analysis of blowdown transients of nuclear power reactors in an equilibrium approximation* – Paper presented at NEA meeting on LOCA computer programs, Ispra, October 1974

FRANCHI, M., GANSS, B., LUCIA, A.C., VOLTA, G. – *Aspetti teorici e sperimentali della localizzazione di sorgenti ultra-acustiche* – Giornata sull'Emissione Acustica, Milano (Italy), May 15, 1974

GARRIBA, S., SILVESTRI, E., VOLTA, G. – *Reliability of a class of stainless steel safety bursting discs* – 2nd National Symposium on Reliability, Perros-Guirec (France), September 17-20, 1974

GRASS, G., FRIZ, G., RIEBOLD, W. – *Blowdown project and previous studies at Ispra connected with LWR-LOCA* – First European Nuclear Conference, Paris (France), April 21-25, 1975

GROSSGUT, W., KOTTOWSKI, H.M., HOLTBECKER, H., RANDLES, J. – *On the process of thermal interaction between molten fuel and coolant* – 2nd Specialist Meeting on Sodium Fuel Interaction in Fast Reactors, Ispra (Italy), November 21-23, 1973 – Proceedings pp 213-247, EUR 5309.e (1975)

HENRY, B. – *Application of Fracture Mechanics to the prediction of rupture behaviour of thin cylindrical structures* – 3rd SMIRT Conference, London (GB), September 1-5, 1975

KOTTOWSKI, H.M., MOL, M.J., MORANDI, A., PANCALDI, E., ZURLI, A. – *Measurement of the liquid metal residual film left behind coolant expulsion in narrow channels* – ANS Fast Reactor Safety Meeting, Los Angeles /California (USA), April 2-4, 1974

LAZARUS, J., NAVARRE, J.P., KOTTOWSKI, H.M. – *Thermal interaction experiments in a channel geometry using Al_2O_3 and Na* – 2nd Specialist Meeting on Sodium Fuel Interaction in Fast Reactors, Ispra (Italy), November 21-23, 1973 – Proceedings pp 89-107, EUR 5309.e (1975)

LUCIA, A.C., REDONDI, G. – *Acoustic emission signals interpretation* – 3rd E.W.G.A.E. Meeting, Ispra (Italy), September 25-26, 1974

LUCIA, A.C., REDONDI, G. – *On the interpretation of acoustic emission signals* – 2nd National Conference on Pressure Vessel and Piping, San Francisco (USA), June 23-27, 1975

LUCIA, A.C., REDONDI, G. – *On the interpretation of the acoustic emission signals* – The American Society of Mechanical Engineers, 96th Winter Annual Meeting, Houston (USA), November 30 - December 5, 1975

LUCIA, A.C., REDONDI, C., BRUNNHUBER, R. – *Stress wave emission source location and characterization by digital methods* – Symposium on Acoustic Emission, Tokyo (Japan), September 2-4, 1974

LUCIA, A.C., SCOPESI, L. – *Prove di misura di emissione ultra-acoustica durante la messa in pressione di valvole sferiche da 34"* – Giornate sull'Emissione Acustica, Milano (Italy), May 15, 1974

MOL, M., KOTTOWSKI, H., SAVATTERI, C. – *Application of boiling liquid metals in industrial processes* – OECD Liquid Metal Boiling Working Group, Risley (GB), October 1-3, 1975

MOL, M., KOTTOWSKI, H., SAVATTERI, C. – *Sodium boiling instrumentation and data acquisition* – OECD Liquid Metal Boiling Working Group, Risley (GB), October 1-3, 1975

NIJSING, R. – *Physical and mathematical modelling of rod bundle thermohydraulics* – Seminar der KTG-Fachgruppe "Thermo- und Fluiddynamik", Bensberg (Germany), March 11, 1975

NIJSING, R., EIFLER, W. – *Axial propagation of coolant temperature perturbations in liquid metal cooled fast reactor fuel bundles* – Liquid Metal Boiling Working Group, Grenoble (France), April 25-26, 1974

NIJSING, R., EIFLER, W. – *Thermal fuel rod transients during postulated reactor accidents* – 1st European Nuclear Conference, Paris (France), April 21-25, 1975

NIJSING, R., EIFLER, W. – *Analysis of temperature fields during a heat transfer transient in a fuel channel with sodium cooling* – OECD Liquid Metal Boiling Working Group, Risley (GB), October 1-3, 1975

NIJSING, R., EIFLER, W., DELFAU, B. – *Laterale dispersis in turbulente stroming tussen twee parallele platen* – Meeting of the Heat Transfer Working Group of the Royal Dutch Institution of Engineers, Wageningen (The Netherlands), November 1, 1974

OHLMER, E. – *Überwachung von Strukturschwingungen in Kernreaktoren mit Methoden der Neutronenrauschanalyse* – Gastvortrag an der Technischen Universität Berlin (Germany), November 11, 1974

OHLMER, E., SCHWALM, D. – *Subassembly fault detection and identification by temperature noise analysis* – Reactor Noise Analysis Meeting, Würenlingen (Switzerland), September 18-19, 1975

PALINSKI, R. – *Messung der Viskosität der Kernschmelze* – Kolloquium zum Projekt Coreschmelzen, Köln (Germany), November 7, 1974

PALINSKI, R., CAPPELLETTI, C. – *Zur Technologie von Stoffwertmessungen an Kernschmelzen* – Kolloquium zum Projekt Coreschmelzen, Köln (Germany), November 7, 1974

PENKUHN, H. – *Der winkelabhängige Gamma-Energiefluss in einem Normalbetonschild* – Reaktortagung des Deutschen Atomforums (KTG), Berlin (Germany), April 2-5, 1974

PUTZEYS, J., REYNEN, J., BLANCKENBURG, J., DE WINDT, P. – *On the thermal stresses in BWR pressure vessel nozzles* – Reaktortagung des Deutschen Atomforums (KTG), Berlin (Germany), April 2-5, 1974

REYNEN, J. – *Finite element methods in fracture mechanics problems* – Seminari di Ingegneria Strutturale, Milano (Italy), April 18, 1975

SAVATTERI, C., KOTTOWSKI, H., MOL, M. – *Steady state boiling code-pressure drop, heat flux and dry-out calculations comparing various two phase flow models* – Liquid Metal Boiling Working Group, OECD Risley (GB), October 1-3, 1975

SCHINS, H. – *The lead-water interaction, its interpretation by the consistent boiling model and its relation to reactor safety* – Reaktortagung 1974 des Deutschen Atomforums (KTG), Berlin (Germany), April 2-5, 1974

SCHINS, H. – *Contribution to the boiling curve of sodium* – OECD Liquid Metal Boiling Working Group, Risley (GB), October 1-3, 1975

SCHINS, H. – *Determination of some sodium properties* – High Temperature Institute, Moskva (USSR), October 10, 1975

SPILLER, K.H., DROSTE, D. – *The behaviour of a nitrified stainless steel surface for the suppression of sodium incipient superheat* – Liquid Metal Boiling Working Group, Grenoble (France), April 24-26, 1974

VINCENTI, E., MANCINI, G., CLUSAZ, A., WOLOCH, F. – *COSTANZA-DRAGON, A dynamic code for the analysis of thermal transients of a HTGR core* – Paper presented at the Winter Annual Meeting of the ASME, New York, November 1974

APPLIED INFORMATICS

Papers presented in scientific periodicals

ARGENTESI, F., DE BERNARDI, R., DI COLA, G. – *Mathematical models for the analysis of population dynamics processes in species with continuous recruitments* – Memorie dell'Istituto Italiano di Idrobiologia, **31**, 245-275 (1974)

FANGMEYER, H. – *Semiautomatic indexing, state of the art* – AGARDograph 179, (AD 776642/1GA), (1974)

FANGMEYER, H. – *BRAESS, Effektivzinssätze V für Wertpapiere mit Jahreskupon – Festlaufzeit bis 48 Monate* – Deutscher Sparkassenverlag Stuttgart (Germany), 1-389 (1974)

FANGMEYER, H. – *BRAESS, Effektivzinssätze III für Festdarlehen – für Nominalzinssätze von 10,5% bis 16%* – Deutscher Sparkassenverlag Stuttgart (Germany), 1-63 (1974)

FANGMEYER, H. – *BRAESS, Effektivzinssätze III für Festdarlehen und endfällige Wertpapiere* – Deutscher Sparkassenverlag Stuttgart (Germany), 1-414 (1975)

FANGMEYER, H., FASSONE, G., GEOFFRION, PERSCHKE, S. – *Les travaux du CETIS dans le domaine de l'Informatique Documentaire – Documentaliste, Numéro spécial 1974, Automatisation documentaire,* ISSN 0012-4508, 47-57 (1974)

Reports

DE WOLDE, H.I., MEELHUYSEN, R. – *DABAMA, a dataset administration program* – Program Description Series, 2, ISP-74-11 (Nov. 1974)

FRITSCHE, M. – *Automatic clustering techniques in information retrieval* – EUR 5051.e (1974)

KOLAR, W. – *The SLC-II language translation package user manual for input* – EUR 5173.e (1974)

MONGINI-TAMAGNINI, C., GAGGERO, G. – *Computer program index* – ISP-74-08 (May 1974)

MONGINI-TAMAGNINI, C., GAGGERO, G. (editors) – *EUROCOPI, on-site programs* – ISP-74-13 (Dec. 1974)

PERSCHKE, S., FASSONE, G., GEOFFRION, C., KOLAR, W., FANGMEYER, H. – *The SLC-II system language translator package – Concepts and Facilities* – EUR 5116.e (1974)

PFEIFFER, M. – *Automatische Suffixanalyse* – EUR 5053.d (1974)

VAN WAUWE, A. (editor) – *CSSL - CETIS scientific subroutine library (Fortran 4)* – Program Description Series No. 3, ISP-72-12 (Nov. 1974)

Papers presented at scientific conferences

ARGENTESI, F., DI COLA, G., GUERRI, L. – *Parameter estimation of a distributed system related to the biomass dynamics in acquatic ecosystems* – International Conference on Mathematical Models for Environmental Problems, Southampton (UK), September 8-12, 1975

BOLOGNANI, M., WEAVING, K. – *A network protocol implementation in structured PL/1* – Spring Technical Meeting, Aalborg (Denmark), May 14-18, 1975

ENDRIZZI, A., DAOLIO, C., PANTI, A. – *DBDYM, data base for dynamically changing structures* – SEAS Anniversary Meeting 1974, Zürich (Switzerland), September 9-13, 1974

ENDRIZZI, A., JALAMOFF, P.. – *The relational approach to data bases. An introduction* – SEAS Anniversary Meeting 1974, Zürich (Switzerland), September 9-13, 1974

GAGGERO, G. – *CARONTE, ICES, GENESYS* – GMD, Bonn (Germany) "Bericht über die erste Arbeitstagung des Projektes SIZSOZ", December 2-4, 1974; pp. 114-122

GAGGERO, G., INZAGHI, A. – *HEATEX-I, an ICES subsystem for thermohydraulic analysis of cooled channels* – 15th Worldwide ICES Users Group Conference, London (GB), September 25-26, 1975

GLODEN, R.F. – *Etablissement d'un développement asymptotique de la solution d'une équation integro-différentielle* – 93ème Congrès de l'Association Française pour l'Avancement des Sciences, Limoges (France), July 5-10, 1974

HELMS, H.H. – *European Communities policy and work in Informatics* – SEAS (SHARE European Association) Annual Meeting 1975, Dublin (Ireland), September 8-12, 1975

MONGINI-TAMAGNINI, C. – *The computer program information centre of the Commission of the European Communities* – International Symposium on Information Systems: Connection and Compatibility, Varna (Bulgaria), September 30 - October 3, 1974

MONGINI-TAMAGNINI, C., GAGGERO, G. – *Software exchange within the European Community* – International Symposium on Structural Mechanics Computer Programs, University of Maryland (USA), June 12-14, 1974

PERSCHKE, S. – *Automatic indexing with the INIS thesaurus – Methodology, evaluation and prospectives for application* – INIS Seminar on Indexing, Luxembourg (Grand-Duchy of Luxembourg), June 25-28, 1974

PERSCHKE, S. VERNIMB, C. – *Feasibility study of automatic indexing of INIS abstracts* – International Symposium on Information Systems: Connection and Compatibility, Varna (Bulgaria), September 30 - October 3, 1974; IAEA-SM-189/24

INFORMATION ANALYSIS SERVICES

Papers presented in scientific periodicals

MATTHES, W. – *Regression filter for signal resolution* – Annals of Nuclear Energy, **2**, 141-147 (1975)

REYNEN, J. – *On the use of finite elements in fracture analysis of pressure vessel components* – Paper presented at the Pressure Vessels and Piping Conference, San Francisco (USA), June 23-27, 1975 – American Society of Mechanical Engineers, **75**, PVP-20-1-9 (1975)

Reports

BLANCKENBURG, J., PUTZEYS, J., REYNEN, J., DE WINDT, P. – *Stress analysis of BWR pressure vessel nozzles* – EUR 5374.e (1975)

HARTMANN, J. – *A method to solve the integral transport equation employing a spatial Legendre expansion* – EUR 5339.e (1975)

MATTHES, W. – *Simulation of transport equations with Monte Carlo* – EUR 5347.e (1975)

NICKS, R. – *Eine Neutronenquelle hoher Intensität mit definiertem Spektrum* – EUR 5120.d (1974)

PENKUHN, H. – *The angular flux of gamma rays in a normal concrete shield* – EUR 5286.e (1974)

PENKUHN, H. – *The gamma shielding of irradiated ^{235}U* – EUR 5335.e (1975)

PENKUHN, H. – *The angular gamma flux in an iron slab shield* – EUR 5373.e (1975)

PONTI, C., VAN HEUSDEN, R. – *MORSE-E, a new version of the MORSE code ESIS* – EUR 5212.e (1974)

REYNEN, J. – *Stress intensity factors for thermally cycled pipes with axial cracks* – EUR 5433.e (MF) (1975)

REYNEN, J. – *Stress intensity factors for HSST thermal shock experiments* – EUR 5434.e (MF) (1975)

Papers presented at scientific conferences

BADER, S., ERDMANN, H., HEHN, G., MERKEL, H., NICKS, R. – *Studies on special problems of fast reactor shielding* – Fast Reactor Shielding, San Francisco (USA), November 16-20, 1975

CANALI, U. – *Calculations for iron-benchmark experiments with Cf and 14 MeV sources* – Specialists' Meeting on Sensitivity and Shielding Benchmark, Paris (France), October 7-10, 1975

HEHN, G., MATTES, M., MATTHES, W., NICKS, R., RIEF, H. – *Shielding benchmark experiments and sensitivity studies in progress at some European laboratories* – 4th Conference on Nuclear Cross Sections and Technology, Washington DC (USA), March 3-7, 1975

DIERCKX, R. – *Importance of transactinium nuclear data (TND) for fuel analysis* – Advisory Group Meeting: "Transactinium Isotope Nuclear Data", Karlsruhe (Germany), November 3-7, 1975

DIERCKX, R., SANGIUSTI, V. – *Unfolding codes for neutron spectra evaluation possibilities and limitations* – Intercomparison of Neutron Spectra Evaluation Methods using Activation Detectors, Petten (The Netherlands), September 22-26, 1975

MARCHAL, A., PERLINI, G., NICKS, R. – *Experimental activities of the European Shielding Information Service* – EURATOM Working Group on Reactor Dosimetry, Bruxelles (Belgium), March 14-15, 1974

MATTHES, W. – *Multigroup cross section adjustment by linear regression* – Specialists' Meeting on Sensitivity Studies and Shielding Benchmark, Paris (France), October 7-10, 1975

PENKUHN, H. – *Die Abhängigkeit des Winkelspektrums von Gamma-Strahlen in einem Eisenschild von der Quelldicke* – Herbstsitzung des Fachausschusses Strahlenschutz, Hannover (Germany), October 30-31, 1975

PERLINI, G., NICKS, R., CAMBIERI, A., CINGOLI, F., PINELLI, T. –*EURACOS II facility in the modified thermal column of the TRIGA MARK II Reactor at the university of Pavia Lena laboratory* – 3rd European Conference on TRIGA Users, Neuherberg/München (Germany), October 29-31, 1974

REYNEN, J. – *Analysis of cracked pressure vessel nozzles* – 3rd SMIRT Conference, London (GB), September 1-5, 1975

RIEF, H. – *An attempt of sensitivity calculation in 3D geometries by Monte Carlo techniques* – Specialists' Meeting on Sensitivity Studies and Shielding Benchmark, Paris (France), October 7-10, 1975

STANDARDS AND REFERENCE SUBSTANCES

Papers presented in scientific periodicals

BENETTI, P., OMENETTO, N., ROSSI, G. – *La fluorescenza atomica nella misura della temperatura nelle fiamme* – La Termotecnica, **2**, 86-89 (1975)

BERTOLINI, G. RESTELLI, G. – *Spectrometry with solid state detectors* – in: Atomic Inner-Shell Processes, **2**, 123-167 Academic Press (1975)

COLOMBO, A. – *Vacuum fusion: aluminium bath method for the correct determination of hydrogen in copper* – Analytica Chimica Acta, **72**, 401-406 (1974)

GUZZI, G., PIETRA, R., SABBIONI, E., GIRARDI, F. – *Cerenkov counting rates of radionuclides for activation analysis purposes* – Journal of Radioanalytical Chemistry, **20**, 751-767 (1974)

MOUSTY, F., GIRARDI, F. – *Dosage des impuretés dans le zinc de haute pureté par activation aux neutrons* – Journal of Radioanalytical Chemistry, **22**, 29-43 (1974)

PICKFORD, C.J., ROSSI, G. – *Determination of some trace elements in NBS(SRM-1577) bovine liver using flameless atomic absorption and solid sampling* – Atomic Absorption Newsletters, **14**, 4, 78-80 (1975)

VERSINO, B., VISSERS, H. – *Dual flame photometric detector (DFPD) – Improvements in the selective determination of Cl-containing organic compounds* – Chrómatographia, **8**, 5-8 (1975)

Reports

GUZZI, G. – *Minutes of the Meeting: Chemical analysis of airborne particulates. Intercomparison and evaluation of analytical techniques* – EUR 5341.e (1975)

GUZZI, G., PIETRA, R., SABBIONI, E. – *Determination of 25 elements in biological standard reference materials by neutron activation analysis* – EUR 5282.e (1974)

MUNTAU, H., CENCI, R. – *Determination of mercury by controlled potential coulometry: an outlay for automatic performance* – EUR 5125.e (1974)

Papers presented at scientific conferences

BUSSE, C.A. — *Recent advances in heat pipe investigation at Euratom* — 5th CHISA Congress, Prague (Czechoslovakia), August 25-29, 1975

BUSSE, C.A., LABRANDE, J.P., BASSANI, C. — *The gas controlled heat pipe: a temperature-pressure transducer* — European Conference on Temperature Measurement, Teddington (GB), April 9-11, 1975; Proceedings Inst. Phys. Conf. Ser. **26**, 7, 428-438 (1975)

CASALINI, TROMBINI, C., SIMONOTTI, L. — *Analisi quali-quantitativa per spettrometria di massa di composti organo mercurici* — XII Congresso Nazionale di Chimica, Santa Margherita di Pula/Cagliari (Italy), September 29 — October 4, 1975

GIRARDI, F. — *Accuracy of chemical analysis of airborne particulates: Results of an intercomparison exercise* — 17th Materials Research Symposium, Gaitherburg, Maryland, USA, October 7-11 (1974)

GUZZI, G., GIRARDI, F., PIETRA, R. — *Automated radiochemical separations, counting and data handling procedures in the analysis of biological specimens* — Convegno sulla Determinazione di Radionuclidi in Campioni Ambientali a Materiali Biologici, Roma (Italy), October 15-17, 1974

JEHENSON, P., BREDAEL, I. — *Necessità di caratterizzare gli apparecchi ultrasonici utilizzati in medicina* — Congresso Nazionale della Società Italiana per lo Studio degli Ultrasuoni in Medicina (SISUM), Ferrara (Italy), November 9, 1975 — Seminar on Perinatal Medicine; session on Technical Aspects and Perspectives, La Spezia (Italy), December 19, 1975

LAURENT, H., LAUER, K.F. — *Vers un Bureau Communautaire de Reference (BCR)* — XVIII Colloquium Spectroscopicun International, Grenoble, France, September 15-19, 1975

ROSSI, G. — *L'uso delle tecniche fotografiche nell'analisi spettroscopica* — Congresso Nazionale A.T.I. (Associazione Termotecnica Italiana), Florence (Italy), September 1974

VERSINO, B., VISSERS, H. — *Dual flame photometric detector (DFPD): Improvements for the selective determination of Cl-containing organic compounds* — Third International Congress of Pesticide Chemistry, Helsinki (Finland), July 3-9, 1974

PROTECTION OF THE ENVIRONMENT

Papers presented in scientific periodicals

ARGENTESI, F., DI COLA, G., VERHEYDEN, N. — *The modelling of biomass dynamics in aquatic ecosystems* — R. Trappl and F.R. Pichler (Editors), Progress in Cybernetics and Systems Research, **1** : General Systems, Engineering Systems and Biocybernetics and Neural Systems, Hemisphere Publishing Corporation (1975)

BECKER, W. — *Zur Humanorientierung biomedizinischer Technik* — Eurospektra, **13**, 4, 121-125 (1974)

GANDINO, C. — *Primi risultati dello studio idrologico sul Lago di Lugano* — Articolo presentato alla Quarta Assemblea Generale dell'Associazione Geofisica Italiana, Roma (Italy), April 3-5, 1975; Rivista Italiana di Geofisica, **2**, 1, 32-36 (1975)

GIRARDI, F., GOETZ, L., SABBIONI, E., MARAFANTE, E., MERLINI, M., ACERBI, E., BIRATTARI, CASTIGLIONI, M., RESMINI, F. — *Preparation of Pb_2O_3 compounds for studies on pathway and effects of lead pollution* — Intern. Journal of Applied Radiation and Isotopes, **26**, 267-277 (1975)

GRANCINI, G., STIEVANO, B.M., GUZZI, G., GIRARDI, F., PIETRA, R. — *The determination by neutron activation analysis of trace elements in sea water in sediment simplex collated in Northern Adriatic Sea* — Memorie di Biologia Marina e di Oceanografia, Nuova Serie, **5**, 4, 77-97 (1975)

PAYRISSAT, M. — *Le dioxyde de soufre: son évolution dans l'atmosphère* — Eurospectra, **13**, 16-22 (1974)

PAYRISSAT, M., BEILKE, S. — *Laboratory measurements of the uptake of sulphur dioxide by different European soils* — Atmospheric Environment, **9**, 211-217 (1975)

SABBIONI, E., MARAFANTE, E. — *Inhibition of enzymatic hydrolysis of end-phosphate DNA by iridium chlorocomplexes* — Bioinorganic Chemistry, **5**, 39-49 (1975)

SABBIONI, E., MARAFANTE, E. — *Heavy metals in rat liver cadmium binding protein* — Environmental Physiol. Biochem., **5**, 132-141 (1975)

SABBIONI, E., MARAFANTE, E. — *Accumulation of cadmium in rat liver cadmium binding protein following single and repeated cadmium administration* — Environmental Physiology and Biochemistry, **5**, 465-473 (1975)

SANDRONI, S. — *I laser nella misura dell'inquinamento dell'aria* — Giornale dell'Ingegnere, **17**, anno 23 (1975)

TOEROEK, I. — *Transient recorder CAMAC dataway interface module* — Nuclear Instruments and Methods, **126**, 109-114 (1975)

VERSINO, B., DE GROOT, M., GEISS, F. — *Air pollution — Sampling by adsorption columns* — Chromatografia, **7**, 6, 302-304 (1974)

Reports

AMIC, S., SOREL, F. — *Program UNIT* — EUR 5424.e

BLAESSER, G. – *Propagation of coherent electromagnetic radiation in the atmosphere* – EUR 5170.e (1974)

BOLLINI, G., GANDINO, C. – *14° Annuario Meteorologico 1972* – EUR 5067.i (1974)

CAPPELLANI, F., MELANDRONE, G., RESTELLI, G., SANDRONI, S. – *Remote detection of atmospheric pollutants by I.R. resonance absorption using tunable diode laser* – EUR 5426.e (MF) (1975)

DE BORTOLI, M., GAGLIONE, P., PECCHIO, E. – *L'esafluoro di zolfo come tracciante atmosferico, Rapporto di attività 1973-1974* – EUR 5429.i (MF) (1975)

DE BORTOLI, M., GAGLIONE, P. – *Environmental radioactivity – Ispra 1972* – EUR 5118.e (1974)

GAGLIONE, P., KOECHLER, C., STANCHI, L. – *POLYP, an automatic device for drawing sequential samples of gas* – EUR 5233.e (1974)

HARTMAN, J. – *RESIDU, a computer code for the evaluation of the mean residence time of water in monomictic lakes* – EUR 5361.e (1975)

MUELLER, K.H. – *Meteorologische Tracer in der Regionalplanung* – EUR 5217.d (1974)

MUELLER, K.H. – *An air quality management system for an industrialized region* – EUR 5290.e (1975)

NORDMEYER, H., LANZETTA, L., NICOLLIN, B. – *Redox- and pH- measurements on recent bottom sediments of Lake Lugano* – EUR 5168.e (1974)

SABBIONI, E., GIRARDI, F., MARAFANTE, E. – *A systematic study of biochemical effects of heavy metal pollution* – EUR 5333.e (1975)

SANDRONI, S., BRAMBILLA, E., CERESOLI, M. – *A calibration device from long path sensors of atmospheric pollutants* – EUR 5472.e (MF) (1975)

ZAMORANI, E., OTTOBRINI, G. – *Particle size distribution by a light scattering instrument* – EUR 5400.e (1975)

ZAMORANI, E., OTTOBRINI, G. – *Electric charge distribution measurements by a mobility spectrometer. Part A – Instrument calibration* – EUR 5449.e (MF) (1975)

Papers presented at scientific conferences

ARDENTE, V., DIANA, E., ROSSI, G. – *Simulazione del processo di eutrofizzazione: il ruolo di alcuni componenti essenziali in un ecosistema lacustre* – Primo Convegno Internazionale sull'Ambiente e sulla Crisi dell'Energia, Torino (Italy), May 8-12, 1974

ARGENTESI, F., DE BERNARDI, R., DI COLA, G. – *Zooplankton population dynamics modelling* – Addendum note to the Proceedings of the First International Congress of Ecology, The Hague (The Netherlands), September 8-14, 1974

ARGENTESI, F., DI COLA, G., VERHEYDEN, N. – *Modelli di dinamica della biomassa in ecosistemi acquatici* – Primo Convegno Internazionale sull'Ambiente e sulla Crisi dell'Energia, Torino (Italy), May 8-12, 1974

BECKER, W. – *Aspekte bioelektrischer Signalkopplung und der Humanorientierung medizintechnischer Entwicklungen* – Lecture and Colloquium at Giessen University (Germany), February 18, 1974

BECKER, W. – *Aspekte der Humanorientierung medizintechnischer Entwicklungen* – Arbeitstagung der Deutschen Studiengruppe für Nukleare Elektronik, Berlin-Steglitz (Germany), September 10, 1974

BECKER, W., HAURIE, Y., KOBUS, L., VAN LOON, L. – *Skinmeter, measuring electrical parameters of the skin with low irritation* – Automatisation des Techniques et des Méthodes de Mesures, Toulouse (France), March 4-8, 1974

BENOIT, R., CAPPELLANI, F., PEDRINI, A., RESTELLI, G., SANDRONI, S. – *Applicazione di sorgenti laser alla rivelazione a distanza dell'inquinamento atmosferico* – Primo Convegno Internazionale sull'Ambiente e sulla Crisi dell'Energia, Torino (Italy), May 8-12, 1974

BENOIT, R., PEDRINI, A., STANCHI, L. – *The electronics associated with a LIDAR system for remote sensing of air pollution* – 2nd Ispra Nuclear Electronics Symposium, Stresa (Italy), May 20-23, 1975; proceedings 237-240; EUR 5370.e

BERVOETS, A., HASENJAEGER, H. – *Notes on experience gained during operation of an acoustic sounder and in interpretation of the records* – Seminar on Interpretation of Acoustic Radar Records, Houston (USA), April 25, 1975

DE GRANDI, G., STANCHI, L. – *Comments on the use of microprocessors and minicomputers in nuclear biomedical and environmental fields* – 2nd Ispra Nuclear Electronics Symposium, Stresa (Italy), May 20-23, 1975 – Proceedings pp 14-16; EUR 5371.e (1975)

FACCHETTI, S. – *Measurements of isotopic distributions in the surveillance of food stuff and investigations on the vegetation* – Strumentazione Attrezzature a Applicazione del Vuoto nella Scienza e nella Tecnologia degli Alimenti, Bologna (Italy), May 15-16, 1975

FACCHETTI, S. – *Analisi isotopica per spettrometria di massa applicata all'inquinamento e alla contraffazione degli alimenti* – XI Symposium International sur "Application de la R.M. dans les Industries Agricoles et Alimentaires, Bologna (Italy), November 12-13, 1975

FACCHETTI, S., GARIBALDI, P., CAGLIONE, P., DE BORTOLI, M. – *La spettrometria di massa nell'identificazione delle sorgenti dell'inquinamento ambientale da piombo* – XII Congresso Nazionale Chimica, Santa Margherita di Pula/Ca (Italy), September 29 - October 9, 1975

FACCHETTI, S., SIMONOTTI, L. – *Variazioni osservate negli spettri di massa di alcuni composti in funzione della pressione* – V Congresso Nazionale del Vuoto, Perugia (Italy), September 29-30, 1975

GANDINO, C. – *Elementi di meteorologia ed idrologia applicate all'ecologia* – Conferenza del Corso di Ecologia, Milano (Italy), January 11, 1974

GANDINO, C. – *Misure idrologiche sul Lago di Lugano* – Terza Assemblea Generale dell'Associazione Geofisica Italiana, Roma (Italy), April 18-20, 1974

GARIBALDI, P., FACCHETTI, S., QUAGLIARDI, A., VANINI, G., GADDO, P.P. – *Benzine addittivate mediante piombo isotopicamente differenziato* – Recent Advances in the Assessment of the Health Effects of Environmental Pollution, Paris (France), June 24-28, 1974

GIRARDI, F. – *Radioanalytical methods in the study of pathway and effect of environmental pollutants* – Centenary Celebrations of the Society for Analytical Chemistry, London (GB), July 16-19, 1974

GEISS, F., BOURDEAU, Ph. – *ECDIN, an EEC data bank for environmental chemicals* – 3rd International Symposium on Chemical and Toxicological Aspects of Environmental Quality, Tokyo (Japan), November 19-22, 1973 – published in: Environmental Quality and Safety, **5**, ed. F. Coulston and F. Korte; G. Thieme, Stuttgart, Academic Press, New York, London 1976

GUZZI, G. – *Description of the research activity of the laboratory of applied nuclear chemistry at Euratom JRC Ispra carried out during 1970* – Convegno sullo Stato di Avanzamento in Italia delle Ricerche nel Campo della "Fotochimica-Chimica e Nucleare-Chimica delle Radiazioni", Roma (Italy), January 19-21, 1975

KNOEPPEL, H., VERSINO, B., TOWN, W.G., SCHAUENBURG, H., PEIL, A., POELMAN, J., GEISS, F. – *Clerc type library search combined with a crossbow structural formula design as output of a GC-MS-computer system for organic micropollutant analysis* – Diskussionstagung der Arbeitsgemeinschaft Massenspektrometrie, Schloss Reisensburg (Germany), September 29 - October 1, 1975

MIRANDA, U., FACCHETTI, S. – *Note on the determination of the origin of antique objects based on the isotopic composition of their lead content* – La Moneta Etrusca, Napoli (Italy), April 20-25, 1975 – Quinto Congresso Italiano del Vuoto, Perugia (Italy), September 29-30 – October 1-2, 1975

MUELLER, K.H. – *An air quality management system for an industrialized region* – IIMI Seminar on "Air Quality Management Systems", Milano (Italy), October 14-18, 1974

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REMOTE SENSING OF EARTH RESOURCES

Papers presented at scientific conferences

CASSINIS, R., GUYADER, M., GALLI DE PARATESI, S. – *Agricultural resources investigations in Northern Italy, Southern France and Madagascar* – ESRO: Symposium on European Earth Resources Satellite Experiments, Frascati (Italy), January 28 - February 1, 1974

DE CAROLIS, C., BALDI, G., LECHI, G., GALLI DE PARATESI, S. – *Thermal behaviour of some rice fields affected by a yellow type disease* – 9th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan (USA), April 15-19, 1974

Authors of the JRC et al. – *Agricultural resources investigations in Southern France and Northern Italy* – 9th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan (USA), April 15-19, 1974

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MEHL, W., STURM, B. – *Ein Programmsystem zur Verarbeitung und Auswertung von ERTS-Daten* – Arbeitstagung über Mustererkennung und kognitive Methoden – *Karlsruhe (Germany), April 9-10, 1975*

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STURM, B., HERZOG, J.H. – *Preprocessing algorithms for the use of radiometric corrections and texture / Spatial features in automatic land-use classification* – Tenth International Symposium on Remote Sensing of Environment, Ann Arbor (USA), October 6-10, 1975

STURM, B., MARACCI, G. – *Determination of beam transmittance and path radiance in the four optical bands of the LANDSAT satellite* – Fifth Conference on Space Optics, Marseille (France), October 14-17, 1975

NEW TECHNOLOGIES – SOLAR ENERGY

Papers presented in scientific periodicals

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GRETZ, J. – *Ancora arduo lo sfruttamento della preziosa energia solare* – Il Giornale, June 25, 1975

GRETZ, J. – *Elettricità ed idrogeno del sole* – Il Giornale, October 13, 1975

Papers presented at scientific conferences

GISSLER, W., LENSI, P.L. – *Investigations on an electrochemical solar cell with a TiO_2 photosensitive electrode* – COMPLES International Meeting, Dhahran (Saudi Arabia), November 2-6, 1975

GISSLER, W. – *Working principle and practical problems of semiconductor-electrolyte solar cells* – Riunione Scientifica Annuale 1975 del G.N.S.M., Catania (Italy), May 28-30, 1975

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FISSILE MATERIAL CONTROL

Reports

ADILETTA, G., BENATTI, N., GUIDOTTI, R., PAOLETTI-GUALANDI, M., PERONI, P., BRESESTI, A.M., BRESESTI, M., D'ADAMO, D. – *Investigations on radioactive fission product correlations: Gamma spectrometry measurements on spent fuel assemblies of the Garigliano reactor* – EUR 5289.e (1975)

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SOLA, A. – *ISOTEX 1, code de calcul de concentrations isotopiques et de rapports de concentrations* – EUR 5111.f (1974)

Papers presented at scientific conferences

BERG, R., FOGGI, C., KOCH, L., KRAEMER, R., WOODMAN, F.J. – *Value and use of isotopic correlations in irradiated fuels* – Symposium on Practical Aspects of R&D in the Field of Safeguards – Roma (Italy), March 7-8, 1974

BRESESTI, A.M., BRESESTI, M. – *Applications of gamma-ray techniques in safeguards* – Symposium on Practical Aspects of R&D in the Field of Safeguards – Roma (Italy), March 7-8, 1974

COPPO, N., DE GRANDI, G., MONTAGNI, M., STANCHI, L. – *Microprocessor based CAMAC data acquisition and processing system* – 2nd Ispra Nuclear Electronics Symposium, Stresa (Italy), May 20-23, 1975 – Proceedings 341-346; EUR 5370.e (1975)

CRUTZEN, S., JEHENSON, P. – *Surveillance and containment techniques* – Symposium on Practical Applications of R&D in the Field of Safeguards , Roma (Italy), March 7-8, 1974

CRUTZEN, S., HAAS, R., JEHENSON, P., LAMOUROUX, A. – *Application of tamper-resistant identification and sealing techniques for safeguards* – IAEA Symposium, IAEA-SM-201/5

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FINZI, S. – *Problemi del ciclo del combustibile* – Rassegna Nucleare di Roma, Roma (Italy), March 21, 1975 – Energia Nucleare, **22**, 6, 326-336 (1975)

FOGGI, C., FRENQUELLUCCI, F., PERDISA, F. – *Correlations between heavy isotopes and fission products in LWR irradiated fuels / A theoretical evaluation* – Symposium on the Safeguarding of Nuclear Materials, Vienna (Austria), October 20-24, 1975

FOGGI, C., ZIJP, W.L. – *Data treatment for the isotopic correlation technique* – IAEA Symposium, IAEA-SM-201/39

KOCH, L., BRESESTI, M. – *Improved method for the verification of the reprocessing input analysis* – Paper presented at the INMM Annual Meeting, New Orleans, June 18-20, 1975

PAOLETTI-GUALANDI, PERONI, BRESESTI, M., CUYPERS, M., D'ADAMO. D., LEZZOLI – *Determination of burnup and plutonium content in irradiated fuels by means of gamma spectrometry measurements of radioactive fission products* – Symposium on the Safeguarding of Nuclear Materials, Vienna (Austria), October 20-24, 1975

SIMONOTTI, L. – *Molecular ion reactions: their application in mass spectrometry at different pressures* – Quinto Congresso di Scienza e Tecnologia del Vuoto, Perugia (Italia), September 29, October 2, 1975

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Papers presented in scientific periodicals

AGAZZI, A., BROGGI, A., GALLI DE PARATESI, S. – *Meccanismi a barre liquide per l'arresto rapido dei reattori nucleari* – Libro dell'Anno 1974, (De Agostini Ed.)

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GUARDINI, S., TASSAN, S. – *Reactivity worth measurements of irradiated fuel clusters in a heavy water moderated assembly* – Energia Nucleare, **22,** 8/9, 444-448 (1975)

OBERHOFER, M. – *Zweites Symposium über Neutronendosimetrie in Biologie und Medizin – Ein Bericht* – Atomkernenergie

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STANCHI, L., TOROK, I. – *Extended use of X-line* – CAMAC-Bulletin

TOROK, I. – *XIR-1 - X interrupt CAMAC module for borer 1533A* – CAMAC-Bulletin

TOROK, I. – *CAMAC tips for IC makers* – CAMAC Bulletin

TOROK, I. – *CAMAC interface module for the biometion type 8100 transient recorder* – CAMAC Bulletin

VAN VELZEN, D., FLAMM, H.J., LANGENKAMP, H., CASILE, A. – *Motion of solids in spouted beds* – The Canadian Journal of Chemical Engineering, **52,** 156-161 (1974)

Reports

ARANOVITCH, E., CRUTZEN, S., LE DET, M., DENIS, R. – *Essais thermiques d'une structure isolante de réacteur* – EUR 5256.f (1974)

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